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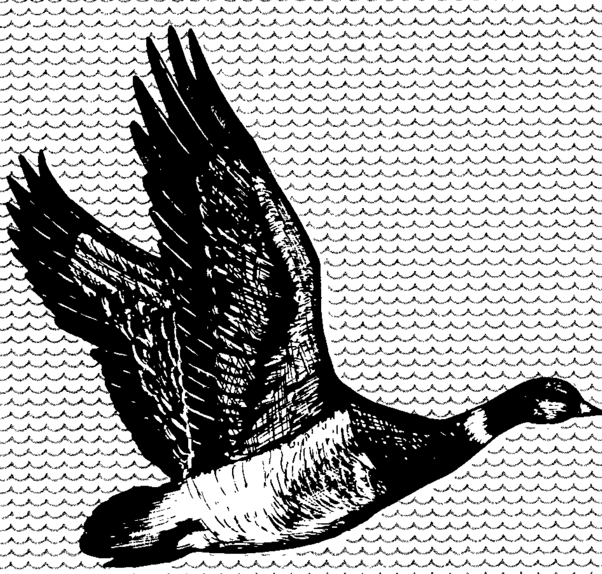
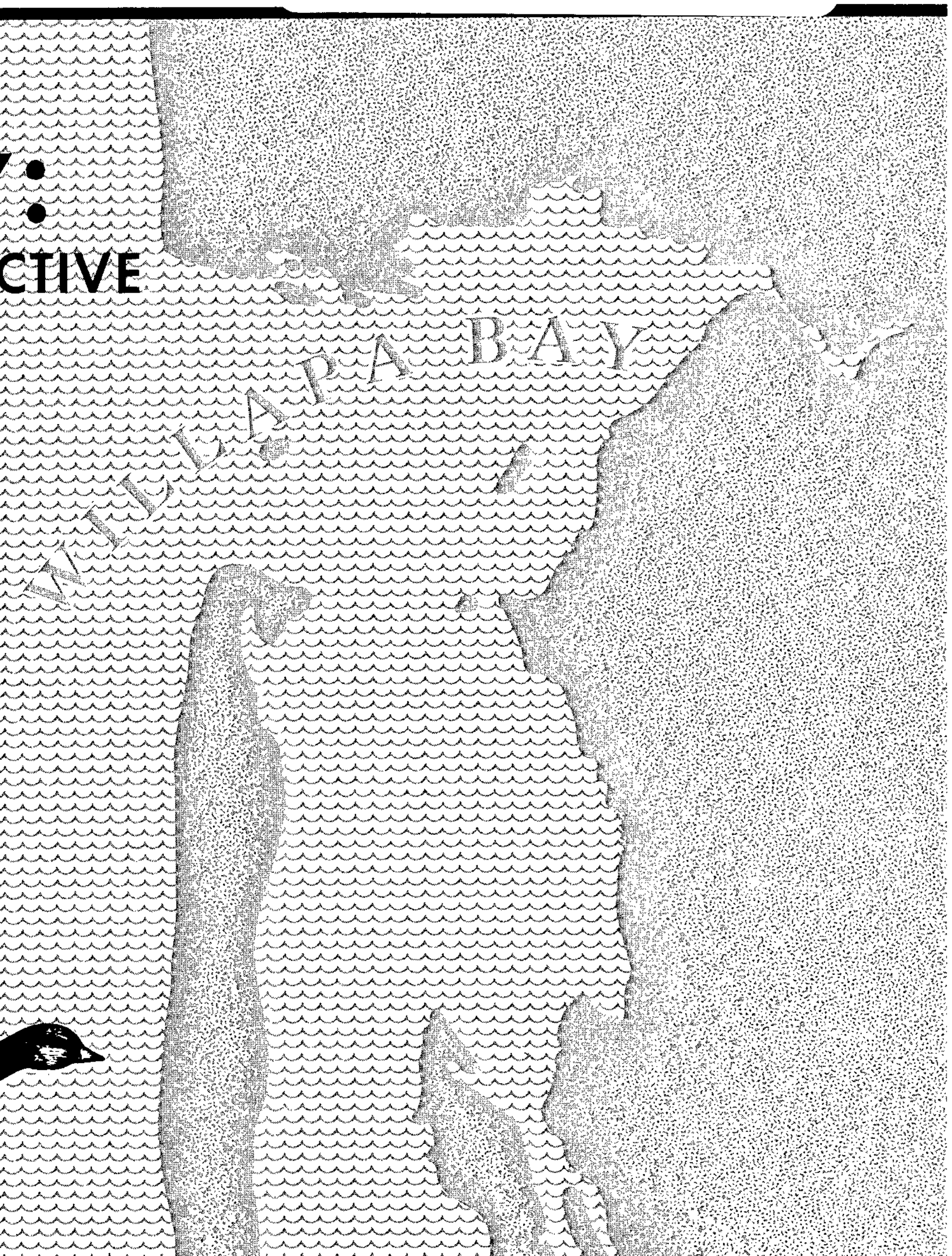
Biological Services Program

FWS/OBS-81/03
April 1981

WILLAPA BAY:
A HISTORICAL PERSPECTIVE AND A RATIONALE FOR RESEARCH





Fish and Wildlife Service

U.S. Department of the Interior

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FWS/OBS-81/03
April 1981

Willapa Bay:
A Historical Perspective
and a Rationale for Research

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PREFACE

This report provides a historical perspective of a Pacific coast estuarine system--Willapa Bay. The intent of the report is to stimulate estuarine research in an area which is relatively undisturbed. Of particular interest is the importance or value of marshes, tideflats, and eelgrass beds to estuarine fisheries and waterfowl. The research findings as determined for Willapa Bay could be applied to other Pacific Northwest estuaries for coastal problems and decisionmaking.

Requests for or questions about Willapa Bay: a Historical Perspective and a Rationale for Research should be directed to:

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SUMMARY

Willapa Bay, originally known as Shoalwater Bay, has been one of the principal centers for production of oysters for the markets and restaurants of San Francisco, Portland, and Seattle since the 1850's. Coincident with early settlement, the basin was initiated to man-induced alterations. Portions of high marshland were converted into pasture by diking and filling, while timber was logged from the adjacent watershed highlands. These alterations culminated in increased commerce and eventually in the development of an important lumber town, Raymond.

The historical and regional geography of Willapa Bay was the subject of a book (Hazeltine 1956). Espy (1977) recorded a charming account of a family living in Oysterville. There have been several treatments of the Willapa Bay oyster industry (Townsend 1896, Kincaid 1951, Sayce 1976), but a general account of the natural history of the bay, especially its estuarine aspects, has yet to be done.

Today, oystering and fishing are the most significant economic activities of Willapa Bay; agriculture is relatively stable; and lumbering has tapered off since the advent of that technique of ecological scalping known as clear cutting. Raymond, as a lumber mill town, is obsolete. The major mills in the region are now at Aberdeen and Hoquiam on Grays Harbor to the north. In the near future, much of the timber anticipated from the clear cut areas of the Willapa Bay watershed will be smaller, uniform-sized logs suitable for pulp and plyboard mills. As a consequence, the channel to Raymond will no longer be maintained since the mills will be abandoned or reduced in significance as they become subsidiary to larger mills nearby. This gradual reduction of mills as the timber is depleted or reduced to an anticipated long-term crop is a familiar pattern in the timber country. It remains to be demonstrated whether clear cutting is an appropriate sustained yield technique as contrasted with selective cutting which destroys less ground cover and forest litter. The conifers of the Pacific Northwest depend, to a large extent, on surface litter rather than nutrients in the soil (Waring and Franklin 1979) and the intensive fertilizing regimen that follows clear cutting must interfere with this natural process in adjacent forested regions. In any event, logging in the Willapa basin has been a major factor in reducing salmon stocks of the basin (Shotwell 1977), and uncertainties remain regarding the fishery and future land practices associated with silvaculture in the basin.

Willapa Bay, however, is more than a body of water surrounded by the fiefs of the barons of the wood products industry. It is an ecological entity, a bay-estuary system that lies coincidentally in a region that has, in the past, been rich in forests. This primary resource is losing its significance as our short-term needs endanger the long-term sustainable yield. But the bay and its potential for supplying renewable resources remain. It is the purpose of this report to suggest information that will be valuable in planning for the management of the aquatic resources of the bay.

In a recent report, (Pacific Northwest Forest and Range Experiment Station 1975), a portion of Willapa Bay including Leadbetter Point is referred to almost in passing with the comment: "...excellent protected bay with sand and

mud substrate. Bivalves (including oysters), crabs, etc., with good populations of an enteropneust, _Saccoglossus_ sp. Introduced population of _Ilyanassa obsoleta_. High priority." While no one can disagree that Willapa Bay should have high priority in research planning, this characterization is meager indeed, and reflects the inadequate information base about Willapa Bay. It implies that we should study _Saccoglossus_, an animal of considerable zoological interest, and a gastropod inadvertently introduced from the Atlantic coast. We probably should, but are these organisms the key to everything else that happens in Willapa Bay? We doubt it. There are many reasons for studying the most important oyster-producing bay on the Pacific coast, but most of the reasons involve the interactions of species with each other and with their environment. Some of these reasons are discussed in the following pages. A case will be made to justify a study about Willapa Bay as an ecosystem with cultural, economic, esthetic, and scientific significance.

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FIGURES

ACKNOWLEDGMENTS

We wish to thank Dr. Jay Watson for encouraging us to prepare this study of the research needs for understanding Willapa Bay, and acknowledge the constructive criticism of representatives of the appropriate Washington State agencies. We are indebted to Dr. James T. Carlton, Woods Hole Oceanographic Institution, for making available to us his material about introduced species in Willapa Bay, and to Dr. J. Arnold Shotwell of Bay Center, Washington, for his assistance and helpful comments.

The following persons from the National Coastal Ecosystems Team, U.S. Fish and Wildlife Service provided reviews or editorial assistance for the camera-ready manuscript: Elaine W. Bunce, John Cooper, Gaye S. Farris, and Wiley M. Kitchens.

INTRODUCTION

PHYSICAL DESCRIPTION OF THE BAY

Willapa Bay is situated on the Pacific coast of Washington between Grays Harbor and the Columbia River estuary (Figure 1). Willapa Bay encompasses about 260 km^2 (100 mi^2) or 31,970 ha (79,000 acres) at mean high water behind a long barrier spit to the north of the Columbia River (Sayce 1976). The main axis of the bay is oriented due north and south about 40 km (25 mi) with a maximum width of about 10 km (6 mi) in mid-bay above Long Island. To the north is a short eastward arm at the mouth of the Willapa River. The bay is a complex estuary nourished by several medium-sized rivers draining from a basin of about 1,865 km^2 (720 mi^2) or 186,630 ha (461,280 acres) in Pacific County, southwestern Washington (Figure 2).

Most of the bay proper is shallow extensive areas of tidal flats. More than 50% of the total high tide surface area is exposed at low tide, and much of the remainder, except for the channels, is only 0.3 to 1.8 m (1 to 6 ft) below mean low tide (Figure 3). The northernmost channel is just below Cape Shoalwater, leading into the Willapa River Channel east of the cape; extending down mid-bay almost to its southern end is the Nahcotta Channel that branches off just south of Cape Shoalwater; Stanley Channel branches off Nahcotta Channel just north of the shoals of Long Island. Channel depths range from 9 to 15 m (30 to 50 ft) with maximum depths of 23 to 24 m (75 to 77 ft) below mean low water. The depths and directions of these channels indicate that they are primarily related to tidal action and secondarily to stream runoff, although Willapa and Stanley Channels are apparently extensions of river channels.

Willapa Bay opens to the sea at its northwestern corner through a broad shallow pass about 10 km (6 mi) wide between Cape Shoalwater and Leadbetter Point. Except for the channel just south of Cape Shoalwater and a smaller channel near Leadbetter Point, much of this region is awash at low tide. For the last several years, Cape Shoalwater has been eroding and, if the process continues, the land and road may be lost back to the base of the bluff. This seems to be an oscillating process, however, and after several years the sand may accumulate, extending the cape southward, and Leadbetter Point will be cut back.

This process is summarized in the Willapa Basin Water Quality Management Plan (Pacific County Regional Planning Council 1974) as follows:

"According to the information in the Corps of Engineers' 1971 Feasibility Report, tidal currents and waves are eroding about three miles of the beach and undermining upland areas of Cape Shoalwater on the north shore of Willapa Bay. The 1880 charts show the bay entrance to be only three miles wide. Between 1887 and 1971, Cape Shoalwater receded 11,700 feet northward and Long Beach Spit receded 2,000 feet southward, averaging 139 feet per year and 25 feet per year, respectively. However, erosion actually ranges from 0 to 250 feet per year. Periods of no erosion are attributed to the extended length of the outer bar and reduced wave action on and resulting stabilization of the inner bar. The main channel then breaks through the northern part of the outer bar, severing the bar, and leaving the southern portion without a sand supply. The severed southern portion of the outer bar is then driven onto the

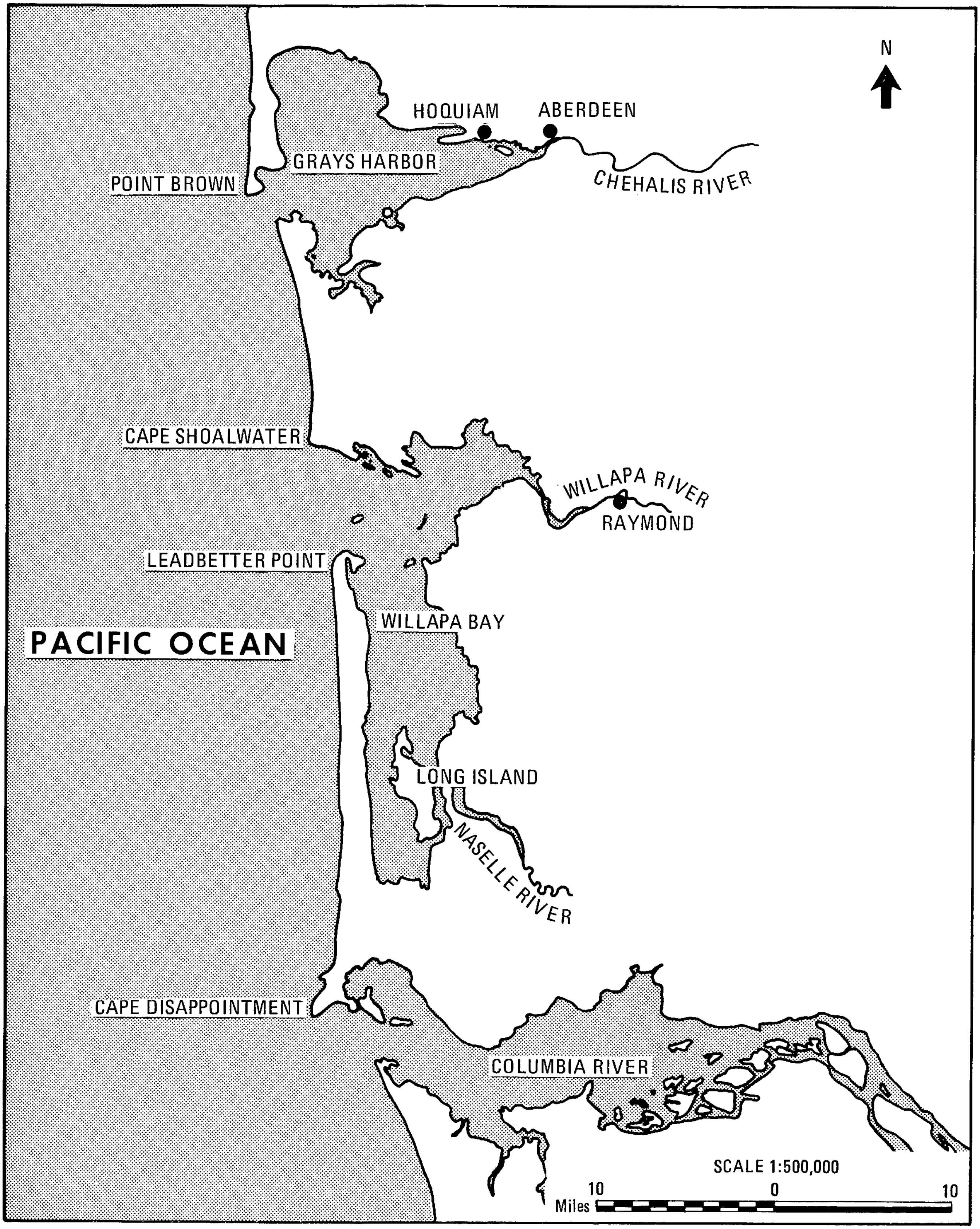


Figure 1. Grays Harbor, Willapa Bay and the lower Columbia River.

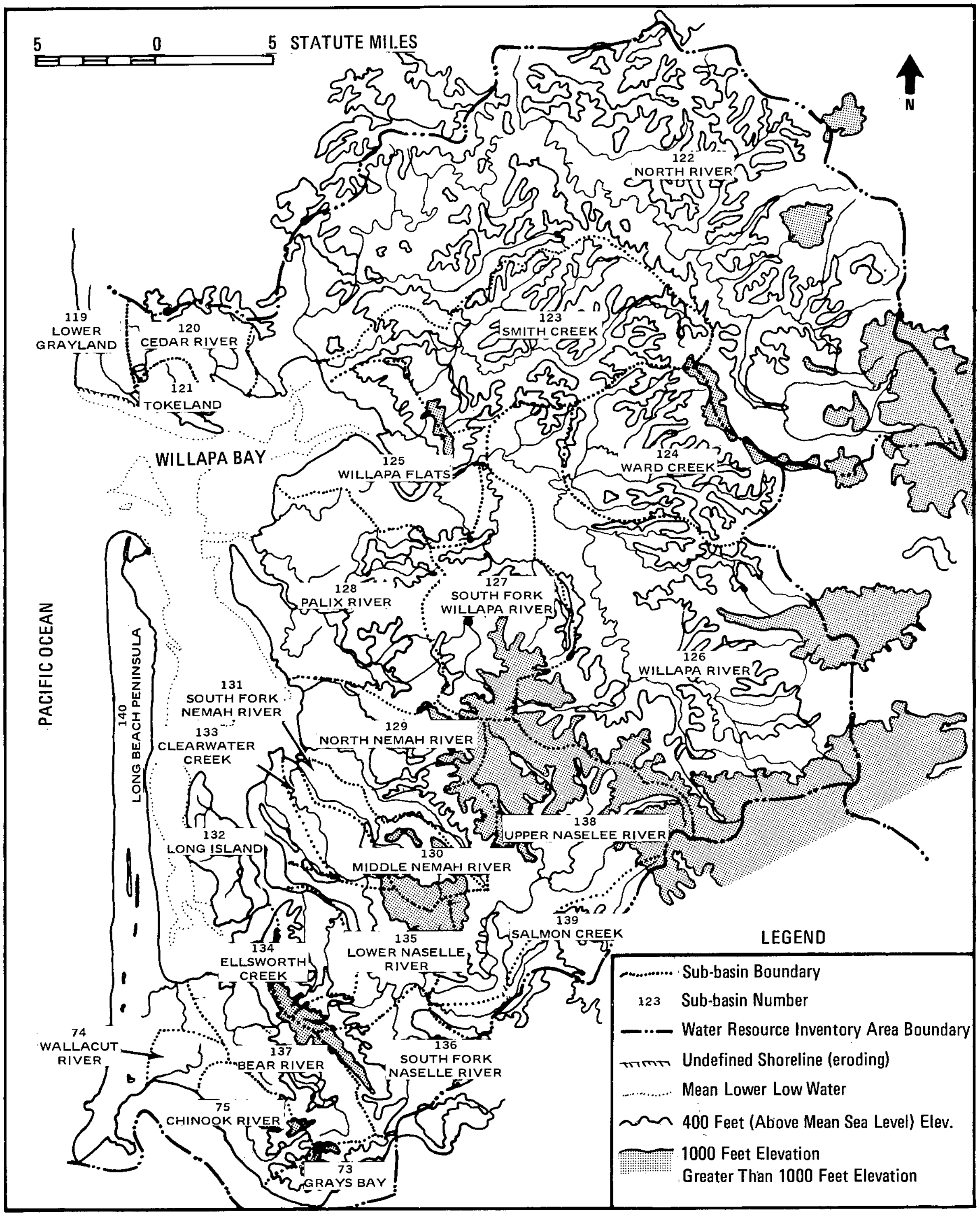


Figure 2. Willapa Bay drainage system. (U.S. Geological Survey Map and Soil Conservation Service Watershed Map.)

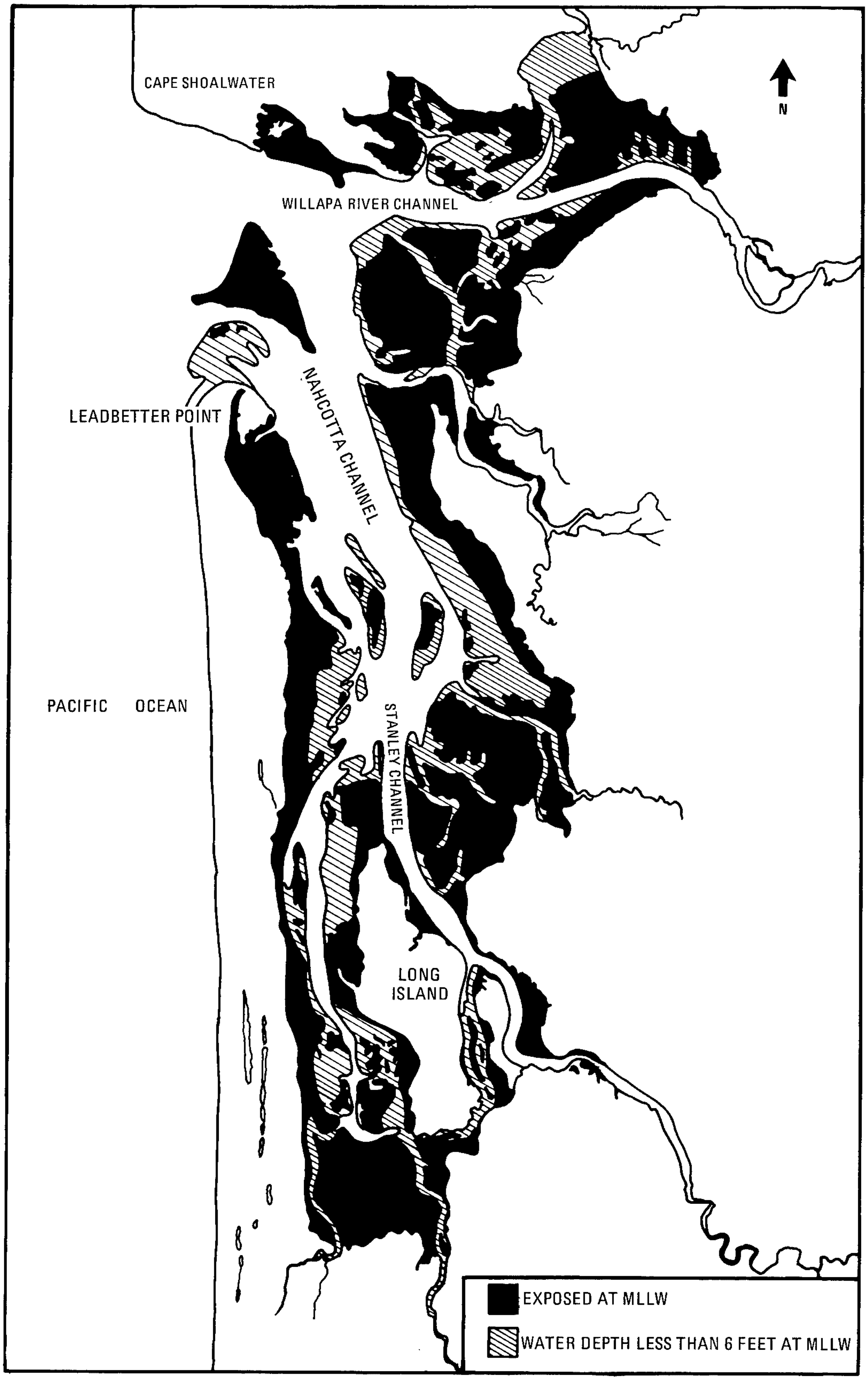


Figure 3. Channels and exposed tidelands of Willapa Bay (Shotwell 1977).

inner bar by ocean waves. The resultant enlarged inner bar crowds the north (main entrance) channel tight against Cape Shoalwater and narrows the channel, causing increased tidal velocities and accelerated erosion of the shoreline. The restricted main channel also tends to force development of a secondary channel to the south near Leadbetter Point. Subsequent widening of the north channel due to erosion of the north bank and the development of the south channel tends to relieve the pressure on the Cape Shoalwater shoreline, causing erosion to diminish. The northern portion of the outer bar then begins to build southward again and the cycle is repeated. This cycle appears to normally take from 13 to 20 years."

The entrance to Willapa Bay is about 45 km (28 mi) north of the mouth of the Columbia River, near enough so that the waters of the bay can be modified by Columbia River effluent during the winter months when the plume of the river is carried north. During the heyday of radioactive contamination of the river from the Hanford Works, Zinc-65 was concentrated by oysters in Willapa Bay and was detected in an employee of the Hanford Works who ate some of these mollusks (Perkins et al. 1960).

Sixteen to nineteen kilometers (10 to 12 mi) north of Cape Shoalwater is the entrance to Grays Harbor, a triangular bay with the big mill towns of Hoquiam and Aberdeen at its apex where the Chehalis River enters the bay. Less is known about the possible effect of waters from Grays Harbor on Willapa Bay than about that of the Columbia River plume.

The bay and its surrounding basin lie in a region of cool, dry summers. The moderate winters are often accompanied by heavy rainfall with occasional snowfall in the lowlands. Annual precipitation on the beach areas ranges from 165 to 216 cm (65 to 85 inches), while areas in the Willapa Hills receive 254 cm or 100 inches/yr (Figure 4). Mean annual runoff ranges from 127 cm (50 inches) in the west and north to about 305 cm (120 inches) in the upper Naselle River Basin. Mean annual runoff for the entire basin is estimated to be 173 cm (68 inches) or 3,400,000 acre-ft/yr (Figure 5). There are often winter floods of short duration, and the mean maximum discharge at the mouth of Willapa Bay is 1,600,000 ft^3/s. Mean daily runoff, however, is estimated to be about 0.004% of the total volume of the bay.

The tidal range in Willapa Bay is 4 to 5 m (14 to 16 ft). In some parts of the bay, there are strong tidal rips and the incoming tide rises over the extensive tidal flats with disconcerting speed. The volume of the bay at mean higher high water is 56,585,900 ft^3; the volume at mean lower low water is 31,169,000 ft^3. The difference, 25,416,900 ft^3, is considered to be the tidal prism, which, according to the U.S. Army Corps of Engineers, Seattle District (1975: p. 20), "means that approximately 45 percent of the water in the bay is emptied into the Pacific Ocean on a tidal cycle from M.H.H.W. to M.L.L.W." This seems to suggest that there is only one tide per day, which is not the case; the mixed semi-diurnal tides of Pacific coast waters result in a discrepancy in the tidal prism volume (i.e., successive tidal prisms are consistently unequal in volume).

There are other factors that inhibit tidal exchange in an estuary the size of Willapa Bay, and the flushing rate (or residence time) remains to be determined, as indicated in the following:

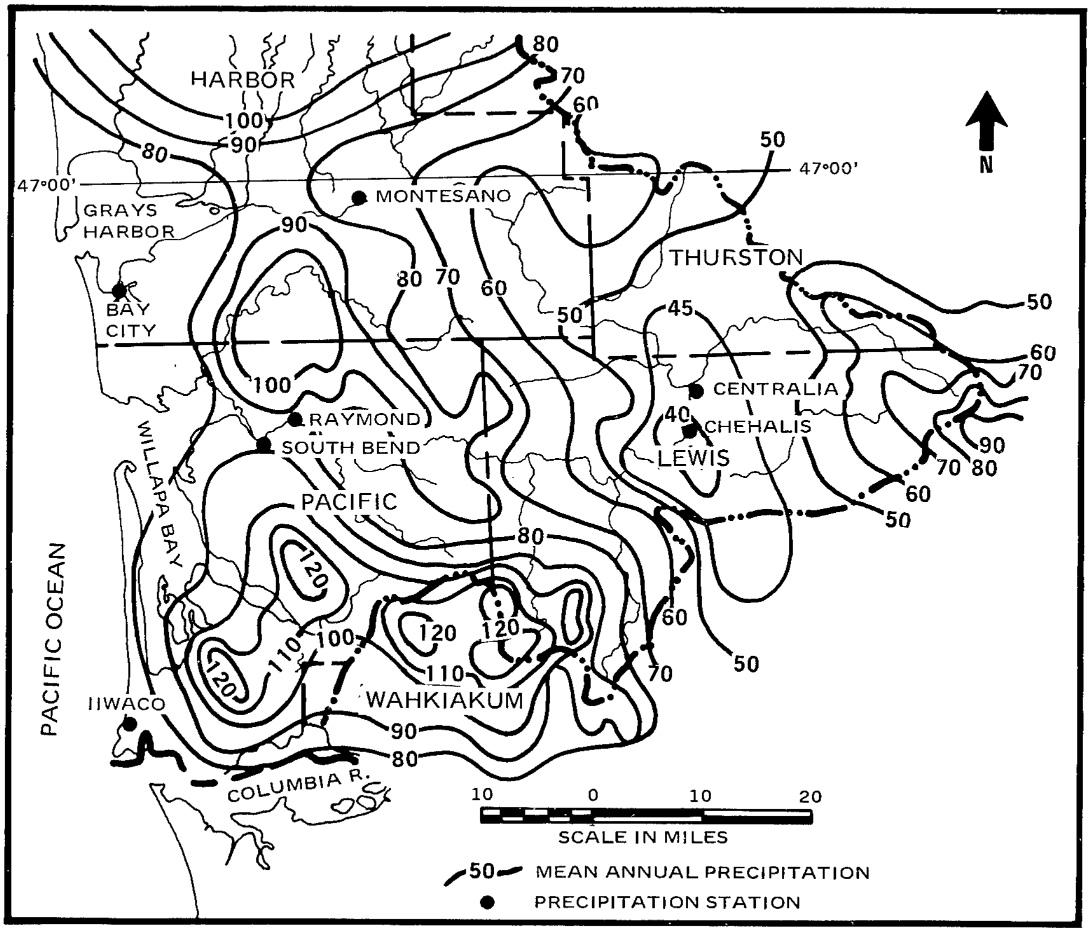


Figure 4. Mean annual precipitation (inches) for the vicinity of Willapa Bay, 1930-1957. (Adapted from Figure 665, Pacific Northwest River Basin Commission 1970).

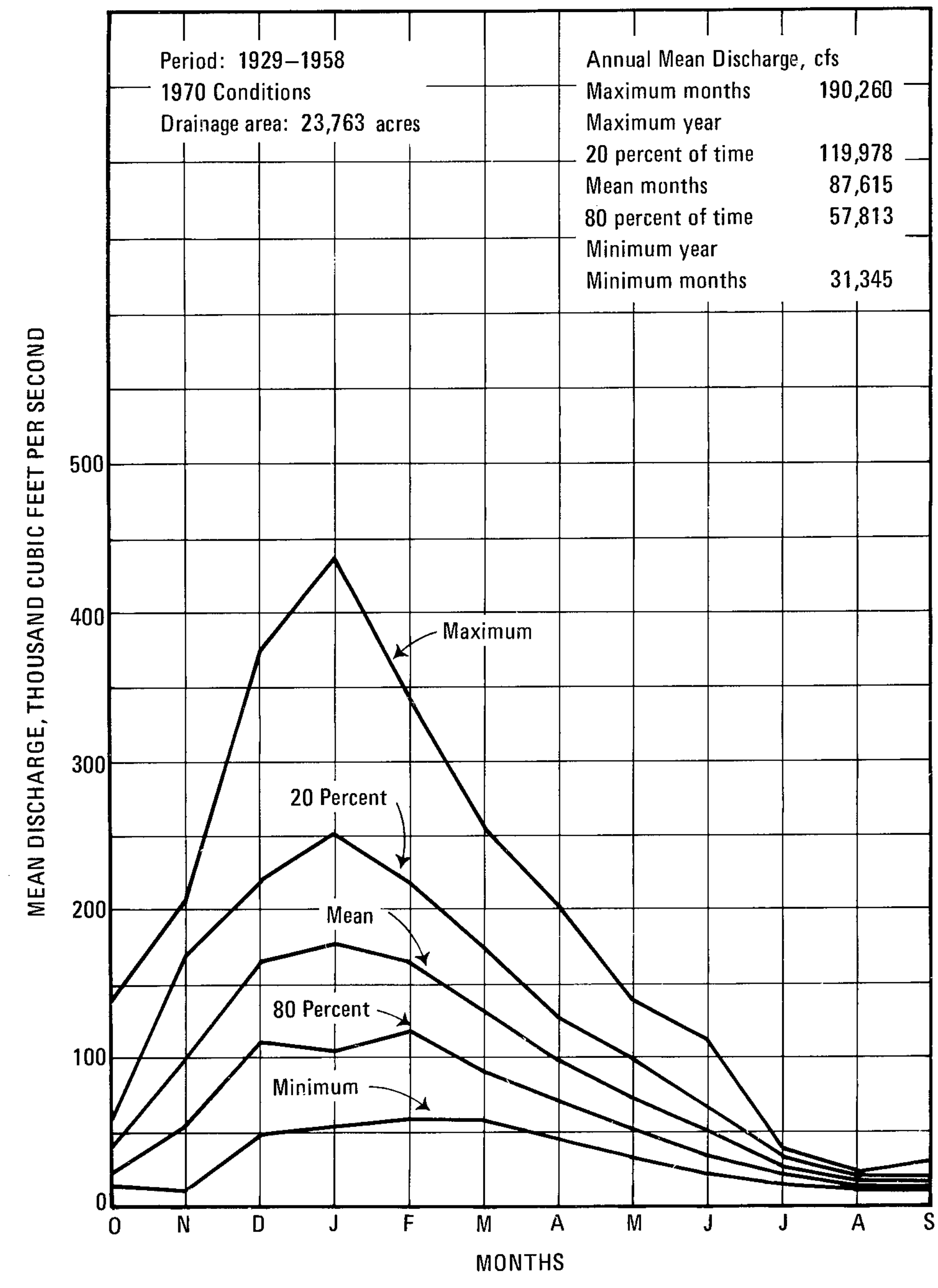


Figure 5. Monthly runoff discharge (thousand cfs) for the vicinity of Willapa Bay. Adapted from Figure 667, Pacific Northwest River Basin Commission 1970.

"While it might appear that the large tidal prism would bring about a fast turnover of bay water, this is not always the case. Conditions in the ocean determine how much of the water exiting the bay will return on the next incoming tide. In the summer, strong northwesterly winds bring upwelled water from the ocean into the bay, promoting a rapid turnover. Storms and high wave action will also promote mixing. At other times, the Columbia River plume, acting as a discrete water mass, prevents much mixing from occurring and the water from the bay moves back and forth for days. The survival of oyster larvae long enough to set in the bay indicates that at times complete flushing must take more than 20 days" (U.S. Army Corps of Engineers, Seattle District 1975: p. 20).

Willapa Bay is fringed by extensive wetlands, including mud flats and salt marshes. The tidal action, which enables regular exposure to air and light, has stimulated the growth of many shore plants, including buttercups, velvetgrass, monkey flower, bulrush, sedges, and tussocks. Plant matter from the marshes is broken up and transported by tidal action into the bay. This plant detritus is evidently a significant contribution to various filter feeders in the bay, especially clams and oysters. Until recently, however, man has not considered that the tidal marsh and adjacent mud flats had any value to nature, let alone himself, and set about filling such areas and converting them to pasture and farm land. About 30% of the original wetlands of Willapa Bay have been "reclaimed" by diking and filling (Figure 6). This process has been assisted by the maintenance of channels by dredging, which has provided a convenient source of material for filling behind the dikes.

FISHERY RESOURCES

Willapa Bay is perhaps the most productive bay on the Pacific coast. It is an optimum environment for many estuarine organisms, particularly the oyster. This productivity is enhanced by the relative freedom from industrial pollution, the water exchange with the sea, and good circulation within the bay.

Oysters were Willapa Bay's first industry; after the Gold Rush days, Willapa Bay supplied the gourmets of San Francisco with the native oyster, _Ostrea lurida_. To this day Willapa oysters are well known although the Japanese or Pacific oyster (_Crassostrea gigas_) is the principal species of economic importance. Before introduction of this species from Japan in 1928 (Korringa 1976), the eastern oyster, _Crassostrea virginica_, was transplanted into Willapa Bay from the Eastern United States in 1894 (Townsend 1896).

Over 50% of the oyster production in Washington is from Willapa Bay (Figure 7). The present status of the oyster industry is summarized as follows:

"Oyster production has traditionally been Willapa Bay's most valuable marine resource. The population of the native oyster which once covered the intertidal areas of the bay has been drastically reduced by overharvesting. The Pacific, or Japanese, oyster is the species cultivated commercially at this time. For many years, Japan was the only source of seed for the Pacific oyster, but local sources of seed are now being developed in the Northwest, including one commercial oyster hatchery on Willapa Bay at Bay Center. In

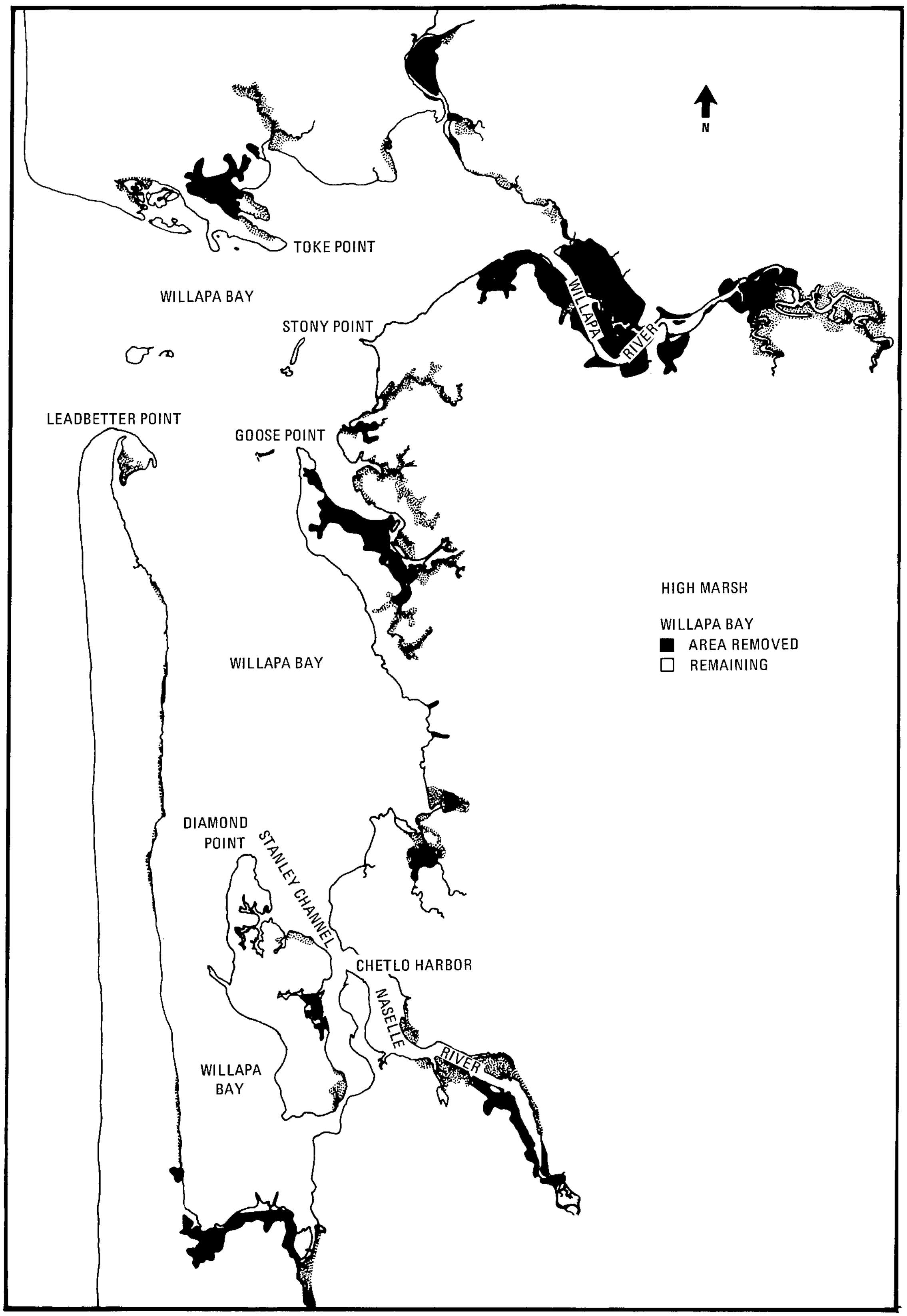


Figure 6. High marsh areas of Willapa Bay (Shotwell 1977).

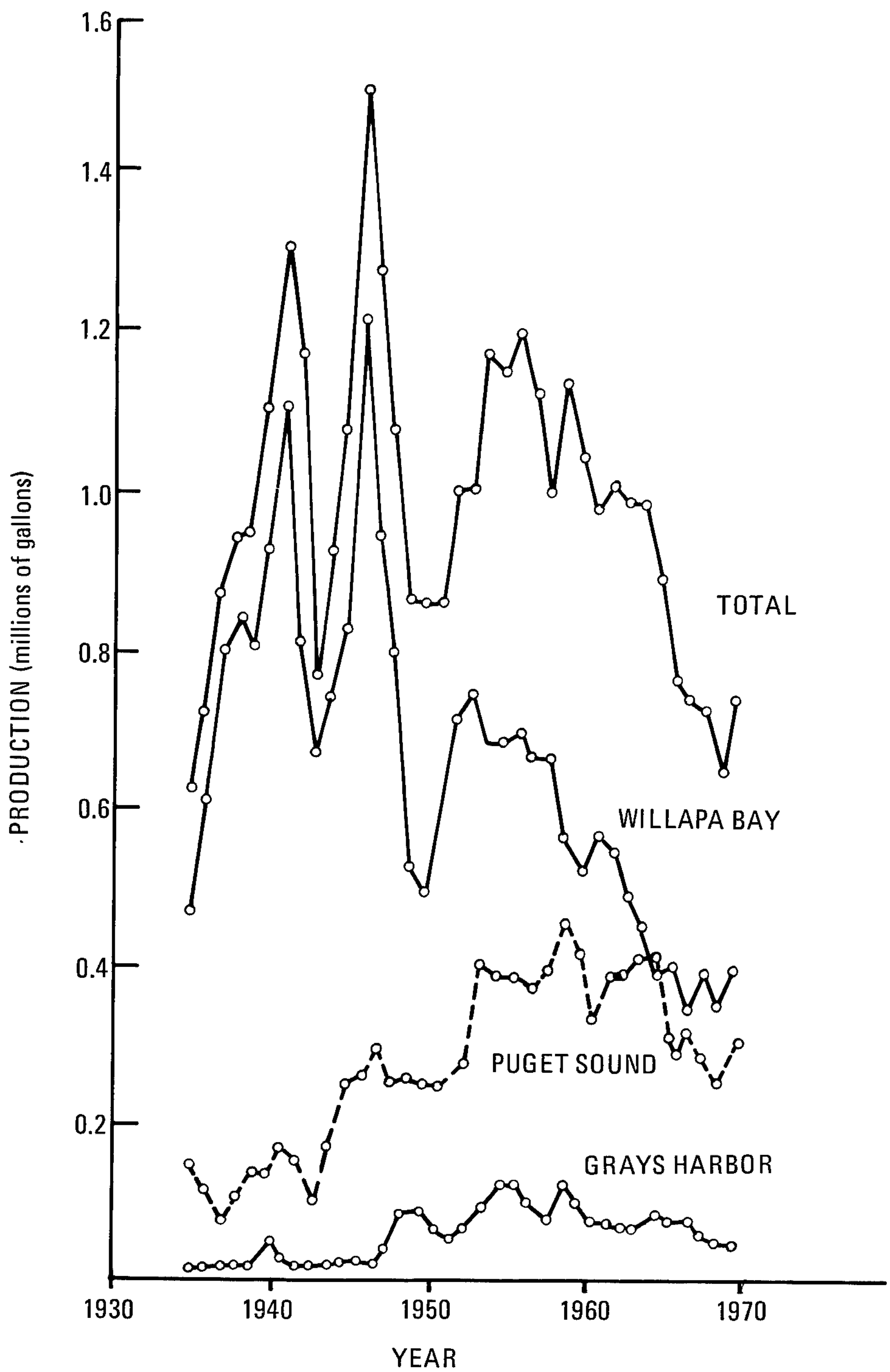


Figure 7. Production (millions of gallons) of Pacific oysters (Crassostrea gigas), 1935 to 1970 (Shotwell 1977).

addition, approximately [4,000 ha] 10,000 acres of intertidal and subtidal lands in Willapa Bay are managed as oyster reserves by the Washington Department of Fisheries, serving as a source of oyster seed at spawning time. The Department maintains a shellfish laboratory at Nahcotta on the Long Beach Peninsula to monitor conditions in the bay relating to oyster production, to advise oyster farmers, and to conduct research on shellfish growth and production.

"At present, approximately [6,000 ha] 15,000 acres of the bay are used for oyster production although [17,200 ha] 42,500 acres are suitable. The oyster seed is planted in the growing areas and is moved before harvest to the fattening areas, which are located mainly in the northern and western parts of the bay.

"According to the Washington State Department of Fisheries, in 1970 the Willapa Bay oyster harvest of 3.5 million pounds was 53 percent of the State of Washington's total oyster harvest. About 30 private individuals or firms are involved in private production with the three largest firms owning about 90 percent of the total oyster production areas.

"Oyster production in Willapa Bay reached its peak in 1946, and has declined since then. One factor contributing to the decline has been widespread oyster mortalities in the bay, a problem which affects both juvenile and adult oysters. Adult oyster mortalities became apparent in 1962-63. Before that time, the adult mortalities were approximately five percent of the total population. By 1964 they exceeded 50 to 60 percent. The mortalities were more noticeable near [in areas subject to] the influence of the Willapa River, giving rise to hypothesis that the cause involved nutrients brought down by the river which initiated toxic phytoplankton blooms. Related factors include tannic [acids] and lignin from log handling and processing operations, which make [increasing the activity of] iron more available in the water, causing the iron to make [which ultimately results in making] nutrients more available. It is also possible that the mortalities are related to spawning, since they often occur immediately after the spawning season" (Northwest Environmental Consultants 1974).

Nevertheless, it appears that the present oyster industry could be expanded, especially in view of past production, as implied in the following comments.

"Yields of from 2,000 to 6,000 pounds of shucked oysters per acre per year occur . . . . However, present indications are that the oyster grounds could produce up to 50 or 60 million pounds per year with more extensive management and favorable growing conditions, provided that the demand were sufficient.

"The decline in oyster meat production has been in part a direct effect of a degradation of habitats. Excessive siltation coupled with water pollution can virtually destroy a bed. Oyster culture is, however, not a completely understood science and opinions differ as to the major reasons for the reductions in productivity of oyster beds" (Pacific County Regional Planning Council 1974).

According to J. Arnold Shotwell (personal communication 27 January 1976), it may not be correct to suggest that the principal cause of the reduced population of Ostrea lurida is overharvesting, since this species is still found in deeper channels of the bay. The significant decline of the native oyster is probably more closely related to economic competition from the larger, faster-growing, introduced Japanese species and the reduction of stock as a result of diking activities and logging practices. Shotwell estimated that about 5,300 ha (13,000 acres) should be considered suitable for oyster culture and harvesting, and that the figure of 17,200 ha (42,500 acres) actually refers to the total area of intertidal lands.

While importation of Japanese seed is still a significant part of oyster culture in Willapa Bay, it has declined steadily in recent years. Natural setting has been an important source of seed in Willapa Bay since 1936, although it too has decreased.

After oysters, the most important shellfish resource of Willapa Bay is the dungeness crab, Cancer magister. The bay evidently serves as an important nursery area for these crabs, since immature crabs occur in abundance on the flats and in the channels throughout the year. In summer, as the water becomes more salty, the crabs move farther up the bay. There is a significant offshore and inshore crab fishery, but because the catch data do not distinguish between Willapa Bay, offshore, and adjacent regions, the contribution of Willapa Bay to this fishery, although obviously significant, is not clearly documented. Many crabs are caught for personal use, but these catch statistics do not enter the records. The 1975 to 1976 season appears to have been a good year for dungeness crabs at least as far south as Eureka. Market prices in San Francisco dropped that year as a result. There appears to be a cyclical fluctuation in the Willapa Bay crab population. Since 1935, annual catches have ranged from 450,000 kg (1 million lb) to more than 1,800,000 kg (4 million lb); peak catches apparently occur every 7 to 13 years (Figure 8). The peak catch of 1969 was about 29% of the entire Washington State catch (Table 1).

Among the other shellfish resources of Willapa Bay is the Japanese little neck (Tapes japonica) or Manila clam, which has become naturalized in Willapa Bay (and many other bays on the Pacific coast). Usually, it is found on gravel bottoms and commercial harvest could be encouraged if suitable habitat were provided. Commercial harvest of this species has declined in recent years. In 1953, the estimated commercial clam harvest (of all species) was 147,000 kg (325,000 lb). There is a significant sport fishery for razor clams (Siliqua patula) on the ocean beaches and for other species on bay shores.

There was a brief flurry of fishing for pink shrimp (Pandalus jordani) in Willapa Bay; in 1957, 38,500 kg (85,000 lb) were caught and processed, but by 1963 the catch had declined, partly due to overfishing, but also because of unfavorable weather. At the present time, shrimp are insignificant in the fishery economy of the bay. However, stocks rebound rapidly from overfishing and may return to a significant place in the fishery under appropriate conservation and management measures.

A summary of the fish landings for Willapa Bay through 1974 is provided by Shotwell (1977). It is interesting to note the large increase in bottom

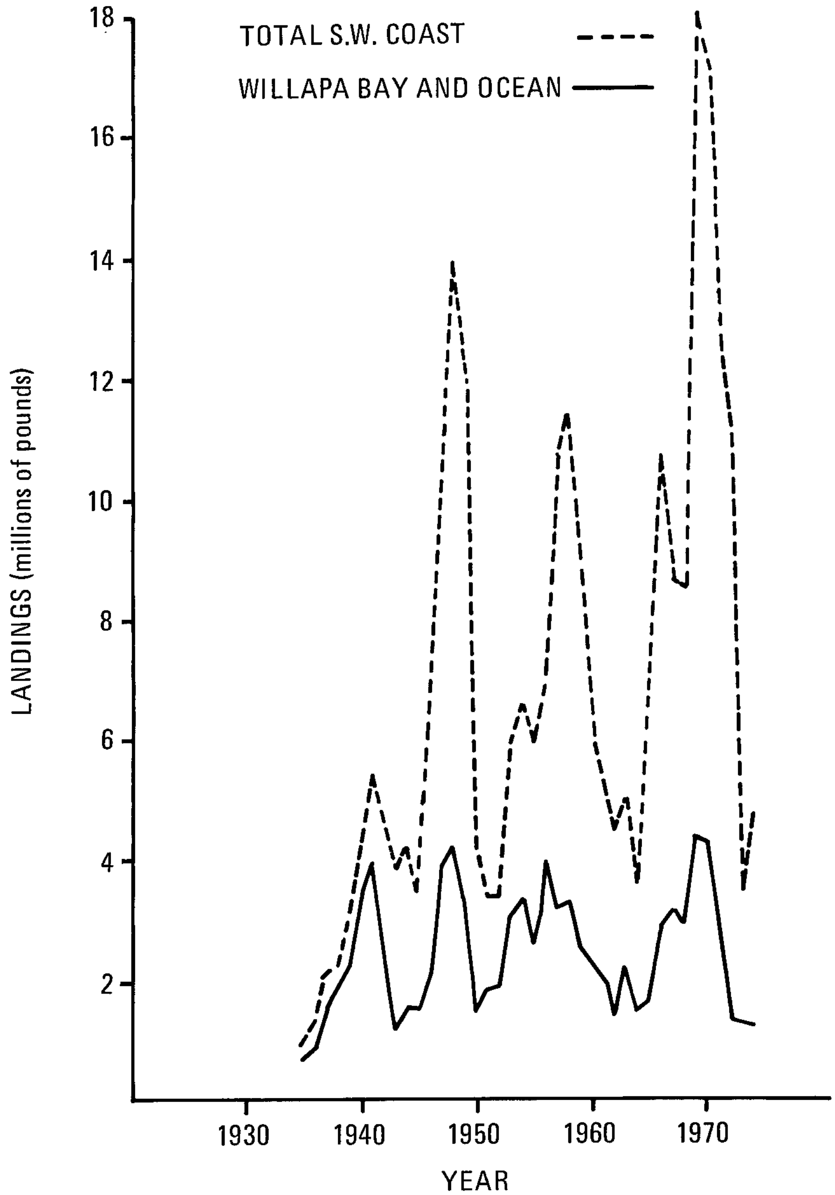


Figure 8. Crab landings (millions of pounds) in Willapa Bay, 1935 to 1974 (Shotwell 1977).

Table 1. Crab landings (lb) for southwest Washington, 1935 to 1974 (Shotwell 1977)[a].

	Area			
Year	Columbia River	Willapa Bay	Grays Harbor	Total
1935		684,842	312,166	997,008
1936		865,194	451,890	1,317,084
1937	3,428	1,441,352	643,231	2,088,011
1938		1,831,716	387,728	2,219,444
1939		2,153,496	620,004	2,773,500
1940		3,341,754	1,134,182	4,475,936
1941	207,164	3,968,152	1,293,222	5,468,538
1942	249,304	2,134,818	2,262,696	4,646,818
1943	56,660	1,052,550	2,732,090	3,841,300
1944	83,326	1,529,196	2,622,316	4,234,838
1945	4,838	1,439,204	1,961,978	3,406,020
1946	17,474	2,031,544	3,674,536	5,723,554
1947	38,184	3,822,288	6,599,880	10,460,352
1948	615,738	4,233,108	9,074,602	13,923,446
1949	950,006	3,204,240	7,694,806	11,849,052
1950	399,440	1,375,788	2,469,894	4,245,122
1951	154,970	1,830,528	1,321,496	3,306,994
1952	82,580	1,892,842	1,373,708	3,349,130
1953	78,263	3,035,435	2,700,206	5,813,904
1954	191,177	3,333,543	3,118,840	6,643,560
1955	209,571	2,457,479	3,269,131	5,936,181
1956	329,386	4,082,936	2,832,542	7,244,864
1957	386,931	3,196,881	7,174,757	10,758,569
1958	691,725	3,300,403	7,473,607	11,465,735
1959	341,602	2,446,493	4,900,608	7,688,703
1960	600,344	2,222,101	3,286,508	6,108,953
1961	346,488	1,912,222	3,211,354	5,470,064
1962	158,633	1,372,678	2,854,597	4,385,908
1963	469,533	2,204,679	2,470,892	5,144,804
1964	187,917	1,406,497	2,004,662	3,599,076
1965	402,292	1,643,301	4,496,120	6,541,713
1966	1,064,182	2,882,102	6,826,676	10,772,960
1967	809,523	3,177,958	4,686,657	8,674,138
1968	1,297,712	2,810,513	4,413,521	8,521,746
1969	1,705,655	4,341,330	11,979,868	18,026,853
1970	2,952,006	4,226,699	9,982,940	17,161,645
1971	2,999,471	2,756,766	6,758,808	12,515,045
1972	1,942,177	2,577,661	6,716,113	11,235,951
1973	485,921	1,312,368	1,636,148	3,434,437
1974	1,145,758	1,256,199	2,363,628	4,765,585

[a]Data from various Washington Department of Fisheries reports.

fish landed in 1973 (Table 2). As indicated by these data, the most important finfish resource of Willapa Bay has been the salmon (Figures 9 and 10).

"Of the six species of Pacific Salmon, three are taken in substantial numbers in the waters of the Basin; silver [Oncorhyncus kisutch], chinook [O. tshawytscha] and chum salmon [O. keta] are the most important (in order of abundance). Landings of salmon in Washington have been characterized by large year-to-year fluctuations.

"For the State as a whole, aggregate landings of all species of salmon show a definite downward trend. Nevertheless, while the State's 1967 landings were 72 percent less than in 1935, the per pound value of the catch had increased 700 percent. As a result, the total value of the catch in 1967 was about 200 percent greater than in 1935. Allowing for inflation implies that the adjusted per pound value of salmon has nearly doubled. This upward trend can be expected to continue.

"Gill net fisheries are conducted in Willapa Bay from late June through November. Virtually the entire catch of coho and chum in this fishery originates in the streams of the Willapa area. A portion of the chinook harvest in June through August is of Columbia River origin. This gill net fishery harvested an average of 14,437 chinook, 20,413 coho, and 15,887 chum annually during the 1966-70 period. An average of 2,291 salmon were landed annually from the streams of the Willapa area in 1966-70.

"A sports fishery is building up at the entrance to Willapa Bay in July and August when chinook salmon enter the bay. A small sports fishing fleet also operates out of Willapa Bay" (Pacific County Regional Planning Council 1974; p. III-42).

In summarizing their discussion of the commercial fishery resources of Willapa Bay, the authors of the Willapa Basin Water Quality Management Plan state the following:

"The potential productivity of the Bay and adjacent waters may be far greater than present harvests of oysters, clams and salmon would indicate. It is not certain that the potential will ever be realized. It is felt by persons familiar with the oyster industry that adequate resources have not been devoted to improving oyster raising techniques. The same holds true for clams and crabs. The fragmented nature and weak financial base of the industry almost dictates that improvements in technique be the result of public efforts as has historically been the case for upland agriculture. Even at that, there are private activities in the mariculture area--primarily related to raising seed oyster to substitute for Japanese imports and to increasing the return rate of hatchery salmon--which show promise and indicate that private investments may provide adequate returns. In any case, the quality of the Basin waters must be maintained or else the potential for increased productivity has no chance of ever being realized" (Pacific County Regional Planning Council 1974: p. III-46).

Shotwell (1977) should be consulted for more information about the fishery resources of Willapa Bay.

Table 2. Finfish landings (lb) in Willapa Bay, 1935 to 1974 (Shotwell 1977).

Year	Finfish							
	Salmon	Sturgeon	Shark	Smelt	Anchovy	Albacore	Bottomfish[a]	Total
1935	1,017,276							1,017,276
1936	1,145,181	38,274						1,183,455
1937	1,024,285	41,224						1,065,509
1938	1,032,879	12,025						1,044,904
1939	661,881	12,958			7,145			681,984
1940	982,619	5,434		170,600				1,158,653
1941	1,729,904	1,634		198,725		149		1,930,412
1942	2,508,988	3,762	246			83,088	380	2,596,464
1943	1,233,116	233	31,719			2,849		1,267,917
1944	927,616	14,037	40,110	8,375		533,727	57,515	1,581,380
1945	1,097,222	13,480	52,814			126,598	18,232	1,308,346
1946	1,472,857	24,396	70,379			92,256	10,460	1,670,348
1947	849,557	9,630	31,645			244,460	20,665	1,155,957
1948	1,206,771	9,479	23,395		436,700	179,167	56,048	1,911,560
1949	886,066	9,788	4,525		448,781	112,222	12,881	1,474,263
1950	1,673,555	15,573	1,554			218,346	3,045	1,912,073
1951	1,875,111	27,927				76,509	1,008	1,980,555
1952	1,852,586	32,166	935			17,780	1,406	1,904,873
1953	1,581,397	34,154	744			513	301	1,617,109
1954	1,849,490	17,007	390				10,091	1,876,978
1955	1,439,978	22,281			570		1,763	1,464,592
1956	1,061,501	73,939				2,457	87	1,137,984
1957	735,081	20,353					9,931	765,365
1958	935,304	15,944				2,323	34,757	988,328
1959	887,215	23,502				6,522	3	917,242
1960	667,037	37,153						704,190
1961	543,284	47,075					72	590,431
1962	581,299	21,610			100			603,009
1963	295,280	29,980				2,923		328,183
1964	559,703	38,401				1,304		639,408
1965	473,330	32,289				16,115		521,734
1966	422,137	76,420				33,621		532,178
1967	553,489	88,364				43,350		685,203
1968	477,652	75,917				50,818		604,387
1969	773,249	109,313				9,384		891,946
1970	1,160,490	139,627						1,300,117
1971	538,395	143,301				8,513	3,715	693,924
1972	942,158	95,604				30,684	2,705	1,071,151
1973	1,460,284	69,031					1,730,710	3,260,025
1974	826,817	53,382				28,055		908,254

[a]Bottom fish include black cod, flounder, ling cod, rock fish, sole, true cod.

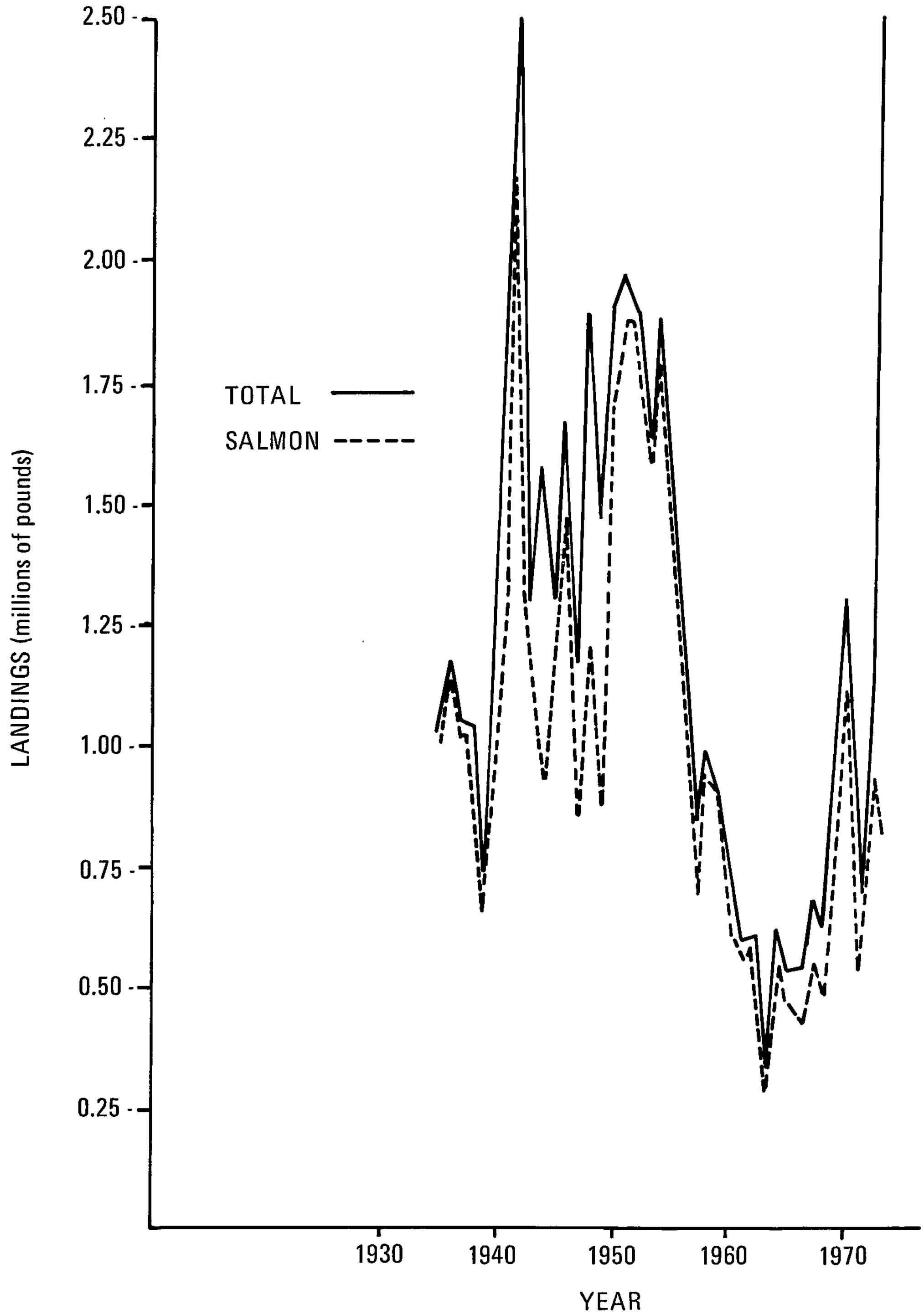


Figure 9. Salmon harvest and total fish landings (millions of pounds) in Willapa Bay, 1935 to 1973 (Shotwell 1977).

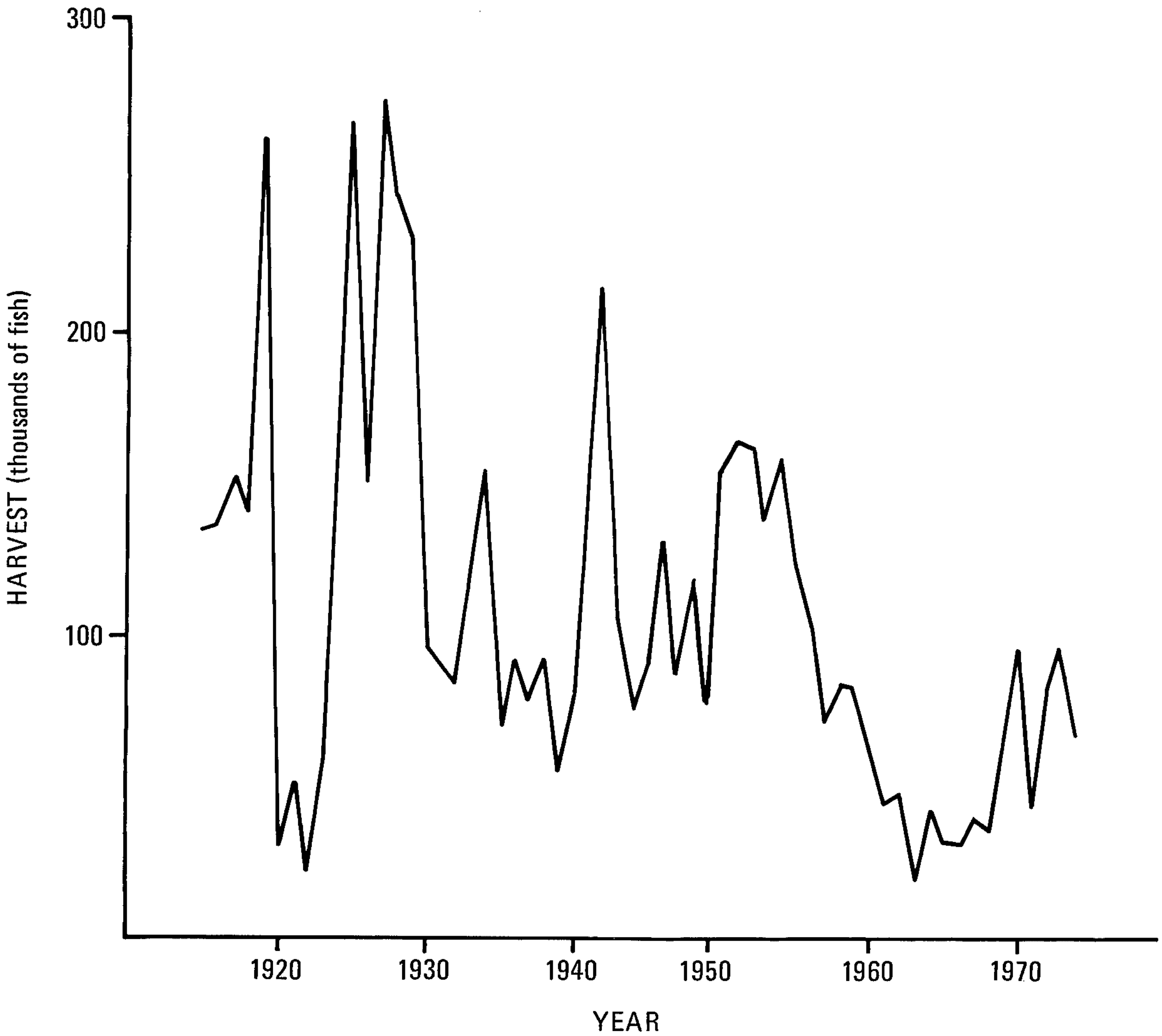


Figure 10. Salmon harvest (thousands of fish) in Willapa Bay, 1915 to 1974 (Shotwell 1977).

INTRODUCED SPECIES

One of the side effects of the introduction of oysters to supplement or replace less desirable native species has been the accompanying introduction of invertebrates and plants. Some of the invertebrates are predators or competitors of the introduced oysters in their home waters. These exotic species may be introduced with seed oysters as juveniles or in egg cases or resting stages. Other organisms appear to have been disseminated as fouling organisms on ship bottoms. Some have probably come in with the packing material for oyster spat, or, in the case of eelgrass, as seeds. Other species, e.g., smooth cordgrass (Spartina alterniflora), have been deliberately introduced, but without documented record.

There have been some spectacular introductions of fishes on the Pacific coast, most notably the striped bass, Morone saxatilis, in San Francisco Bay in 1879, and the American shad, Alosa sapidissima, in the Sacramento and Columbia Rivers in 1871. The shad reached Alaskan waters by 1891 and is now one of the established members of the fish fauna of Willapa Bay. The striped bass, however, is "not common" north of Coos Bay, but there are two records from British Columbia (Hart 1973) which suggest it may turn up in Willapa Bay occasionally.

Comparatively few introductions of marine invertebrates and plants have been completely beneficial. Man's hope for an ideal, fast growing, good-flavored oyster that requires a minimum of care in cultivation is yet to be realized. There are few years when natural reproduction of the oyster stocks of Japanese origin in Willapa Bay occurs, and more often than not, recruitment must be accomplished by hatchery-reared larval stocks. The introduction of the eastern oyster met with a disaster (referred to as a "red tide") in 1919 (Sayce 1976), which obliterated the stock, and the Japanese or Pacific oyster, introduced in about 1928, is at best a tentatively established immigrant. At the same time, however, some oyster pests, like the Japanese oyster drill, Ceratostoma inornatum, have succeeded all too well (Chapman and Banner 1949), and the oriental little neck clam, Tapes japonica, has almost completely replaced the native species Protothaca staminea in the Pacific Northwest, including Willapa Bay.

It is not always certain whether a species, suspected to be exotic, has been introduced or is successfully established. Often successful introductions have been claimed on the basis of a few adult specimens from a single season, without proof of reproduction or establishment of a population. The crabs, Carcinus maenas and Rhithropanopeus harrisi, seem to be an example of such a sporadic record for Willapa Bay. Because of the inadequate base line documentation of the biotic composition circa the early decades of the nineteenth century (when the region was tentatively colonized by the Russians from the Asiatic mainland), and the paucity of verifiable accurately documented specimens, it is not always certain whether a given species is indeed an established immigrant, a recently introduced species, or one that has been there all the time. Because of the demonstrated ability of some introduced species (e.g., the striped bass and the Japanese little neck clam) to replace native species or fill apparently unoccupied niches, a high level of systematic competence is required to be certain of the exact indentity of many of the commonest species of marine invertebrates. An example is the Japanese little neck clam which at first was thought to be an unrecognized native

species and was accordingly named Paphia bifurcata. Even in Europe, where there has been sophisticated knowledge of the taxonomy of the flora and fauna of nearshore waters and estuaries since early in the nineteenth century, exotic species have remained unrecognized as such for many years. A classic example is the crab, Rhithropanopeus harrisii (now identified as an introduction on the Pacific coast from San Francisco to Coos Bay), which was long considered to be an endemic species in European waters under the name Heteropanope tridentatus.

The problem of non-native or introduced species in terms of environmental impact by estuarine modifications such as diking; filling or dredging; or the use of herbicides, fertilizers, or both in the watershed cannot be overemphasized. Not only must we be able to recognize whether a species is native or exotic, but we must also understand the physiological ability of an exotic species to adapt to changes or adulterations, in some cases to the disadvantage of native species. We have adequate demonstration of the potential of introduced species to complicate management problems in various parts of the world. An introduced species of special concern in Willapa Bay is the short eelgrass, Zostera noltii, which tends to grow at the level above the indigenous Zostera in the Ruppia zone, where it may accelerate sedimentation at the expense of native vegetation.

According to James T. Carlton (personal communication, Woods Hole Oceanographic Institution, Woods Hole, MA 02543), who has critically studied introduced species of marine invertebrates on the Pacific coast of North America, there are at least 18 species of introduced invertebrates in Willapa Bay (Figure 11), and he considers that there are probably more, especially in less adequately studied groups. Of the 18 species recognized as non-native in Willapa Bay, 13 are mollusks (Figure 12). A list of the introduced marine invertebrates and plants in Willapa Bay, with their probable origin and means of dispersal, has been compiled by Dr. Carlton (Table 3). He summarizes the occurrence and distribution of many of these species in Willapa Bay as follows.

Two areas in Willapa Bay are especially rich in exotic species: the clay-mud flats at Goose Point, Bay Center, on the east shore; and the floats, pilings, and jetties at Nahcotta, at the south end of the bay. The following comments are by way of example only; all of the species listed here may be found elsewhere in Willapa Bay as well.

At Goose Point, the Atlantic boring clam, Petricola pholadiformis, occurs in hard sticky clay in the high intertidal zone, along with the native boring clam, Platyodon cancellatus (only one other population of the Atlantic Petricola occurs on the Pacific coast--in San Francisco Bay). On the mudflats is the Atlantic mudsnail, Ilyanassa obsoleta (= Nassarius obsoletus). For some reason, the Japanese mudsnail Batillaria has not become established in Willapa Bay, although it is abundant in Tomales Bay. Shells of the Atlantic soft-shell clam, Mya arenaria, and the Japanese oyster, Crassostrea gigas, are common. Most prominent of the exotic species, however, are great beds of the short and narrow-bladed Japanese eelgrass, Zostera noltii, often occurring in patches intermixed with the broader and longer bladed Zostera marina, a native species.

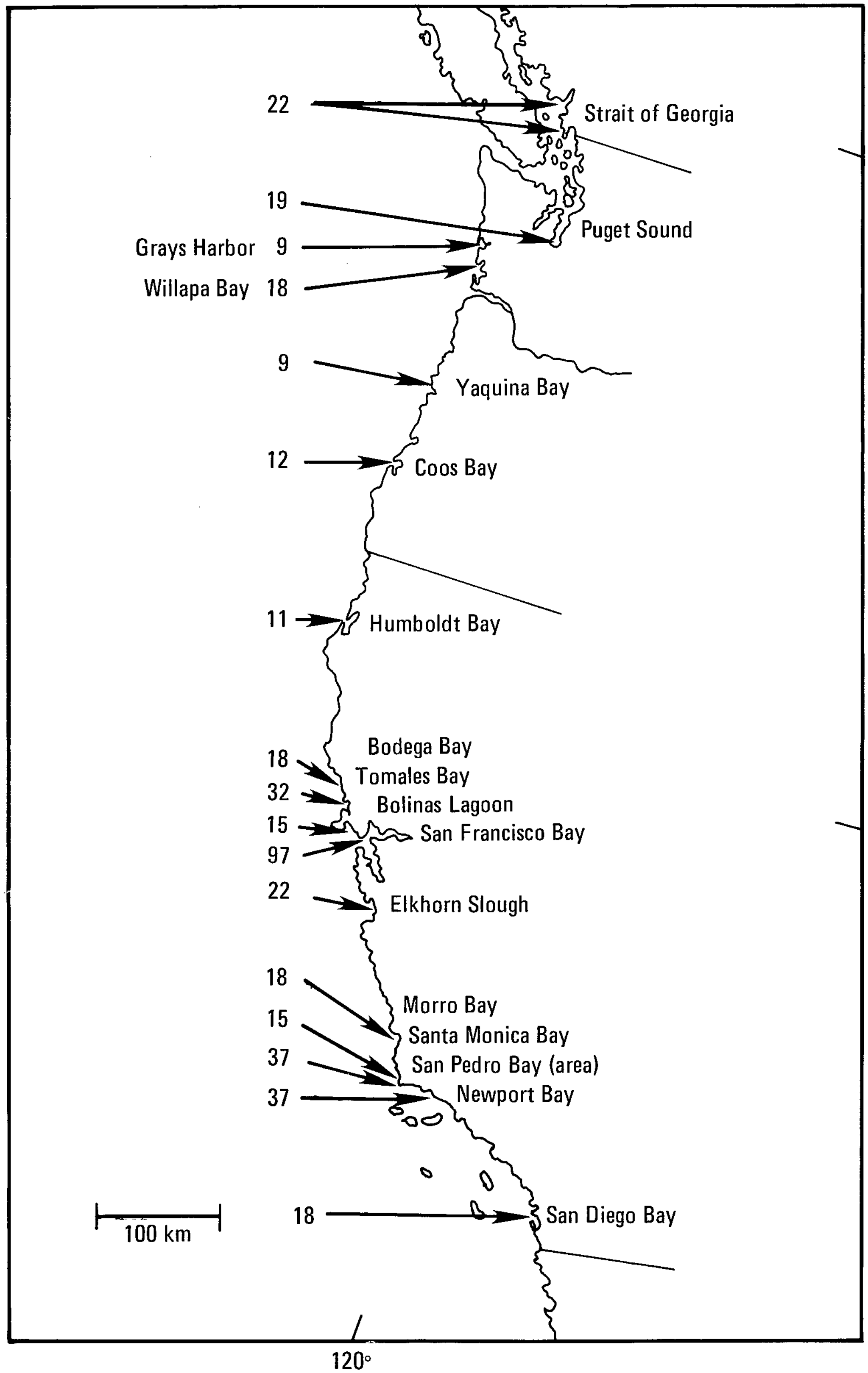


Figure 11. Introduced invertebrates (numbers of species/locality) on the Pacific coast of the United States (courtesy of J.T. Carlton).

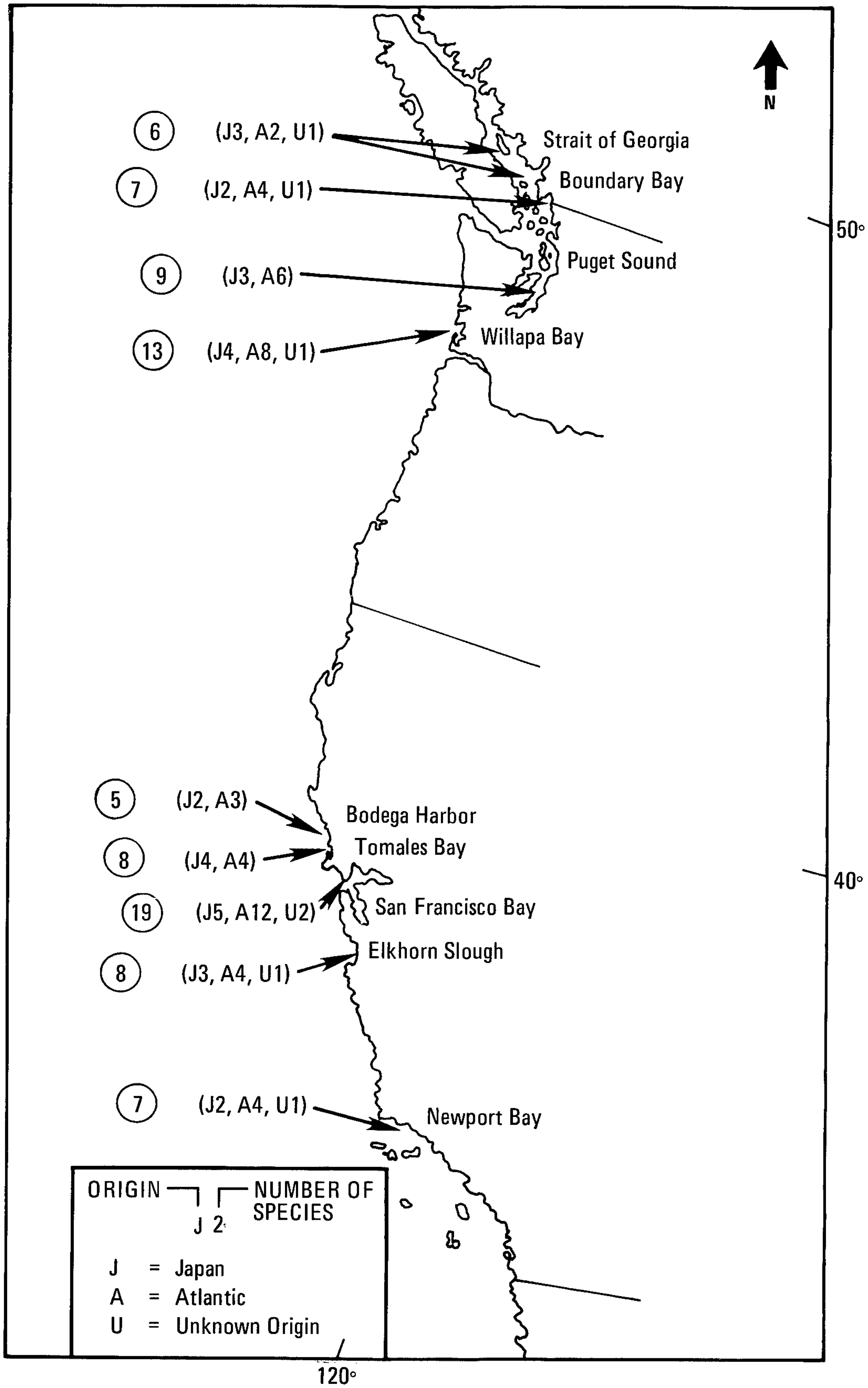


Figure 12. Introduced mollusks (number of species/locality) on the Pacific coast of the United States (courtesy of J.T. Carlton).

Table 3. Introduced (exotic) marine invertebrates and plants of Willapa Bay Washington, origin, and mechanism of dispersal (adapted from James T. Carlton).

Species	Origin	Dispersal mechanism
Porifera		
Microciona prolifera	A[a]	O[b]
Coelenterata		
Anthozoa		
Haliplanella luciae	J/A	O
Mollusca		
Gastropoda		
Cecina manchurica	J	O
Crepidula fornicata	A	O
Crepidula plana	A	O
Ilyanassa obsoleta	A	O
Ceratostoma inornatum = (*Ocenebra japonica*)	J	O
Urosalpinx cinerea	A	O
Ovatella myosotis	A	O
Pelecypoda		
Crassostrea virginica	A	O, local population at Naselle River
Crassostrea gigas	J	O, sporadic reproduction since 1930
Mya arenaria	A	O, intentional plantings (1880's) from San Francisco Bay
Tapes japonica	J	O
Petricola pholadiformis	A	O
Teredo navalis	U, A?	S, perhaps via San Francisco Bay
Arthropoda		
Crustacea		
Copepoda		
Mytilicola orientalis	J	O
Isopoda		
Limnoria sp.	J	O, in wooden seed boxes with oysters; and/or S
Cymodoce japonica[c]	J	O, 1922 record
Cirripedia		
Balanus improvisus[c]	A	O, 1955 record
Decapoda		
Carcinus maenas[c]	A	O, one report 1961

Continued

Table 3. Concluded.

Species	Origin	Dispersal mechanism
Ectoprocta (Bryozoa)		
Schizoporella unicornis	J	O
Tunicata		
Botrylloides sp.	U	O?
Brown algae		
Sargassum muticum	J	O, and/or on boats from northwest
Seagrass		
Zostera noltii	J	O (=*Z. japonica*?; *Z. americana*)
Emergent grasses		
Spartina alterniflora	A	

[a] A = Atlantic, J = Japan, U = Unknown
[b] O - with commercial oyster importation, S - with shipfouling/boring organisms.
[c] - establishment uncertain in Willapa Bay (reproductive populations not confirmed).

Additional notes:

- o A number of Japanese mollusks have been taken alive in Willapa Bay as either direct interceptions or strays from oyster plantings. These include the whelks, *Rapana thomasiana*; and *Thais clavigera*; the jingle shell, *Anomia chinensis* (= *Anomia lischkei*); and the clam, *Trapezium liratum*.

- o The Atlantic lobster, *Homarus americanus*, was planted in Willapa Bay in 1889 (never to be seen again).

- o Far more exotic species than are now recognized in Willapa Bay may be expected: in particular, these include species of sponges, hydroids, flatworms, polychaetes, amphipods, and bryozoans. No introduced polychaetes are recorded from Willapa Bay, but a number of species are likely present, especially spionids (of the genera *Pseudopolydora*, *Polydora*, and *Streblespio*) introduced with Japanese and Atlantic oysters. A spionid that commonly occurs with *Petricola* at Bay Center may be exotic, for example.

At Nahcotta, the floats and tires are rich with introduced species. In the summer, great colorful sheets of a colonial tunicate, Botrylloides sp. (introduced perhaps from either the Atlantic coast or Japan, but certainly not native) cover all available surfaces in yellow, orange, purple, white, and beige. Also on the floats or subtidally nearby are the Atlantic sponge, Microciona prolifera (only known elsewhere on the Pacific coast from San Francisco Bay); the Atlantic slipper shell, Crepidula plana; the Japanese oyster, Crassostrea gigas; the Japanese bryozoan, Schizoporella unicornis; the Japanese anemone, Haliplanella lucia; the shipworm, Teredo navalis (whose original home may have been the North Atlantic Ocean), the boring isopod, Limnoria (not native, but of uncertain species); and the Japanese brown alga, Sargassum muticum. (The Japanese sphaeromatid isopod, Cymodoce japonica, was collected at Nahcotta in 1922 by Trevor Kincaid, but no one has ever systematically explored the isopod fauna of Willapa Bay, so we do not know if it is still present.) Under piles of discarded oyster shells along the beach and jetties, a few inches down where there is some accumulation of organic debris, the small Japanese snail, Cecina manchurica, can be found along with the North Atlantic pulmonate snail, Ovatella myosotis [= Phytia setifer].) Both were introduced with oysters. Cecina does not directly occur with oysters in Japan; but it may have found its way to the Pacific Northwest through the practice in Japan of piling up wooden cases of seed oysters (destined for the United States) on high intertidal beaches.

PREVIOUS RESEARCH IN WILLAPA BAY

Although Willapa Bay has been an important oyster-producing area since the beginning of settlement in the 1850's, there has been surprisingly little research on the bay or its biota except for gathering of fish catch records, studies of oyster spawning, extent of oyster beds, and related matters. For a bay the size of Willapa (in total size larger than all Oregon estuaries except the Columbia combined), this lack of scientific interest is difficult to understand except in terms of more urgent or interesting priorities near Seattle. Obviously, however, here is a gold mine for students needing thesis problems.

The only comprehensive report on Willapa Bay to date is the "National Estuary Study, Vol. III" (U.S. Fish and Wildlife Service 1970). This document provides a general ecological description of Willapa Bay. However, it lacks references, so it is not certain how much depends on previous information and how much may be presented for the first time. The map of eelgrass distribution, for example, appears to be an original contribution based on aerial surveys.

More recently, there have been two environmental appraisal reports. The first of these is the Willapa Basin Water Quality Management Plan, prepared for the Pacific County Regional Planning Council (1974), to meet the local planning requirements for control of industrial pollutants and wastewater effluents. The ecological aspects of Willapa Bay are considered, but these are only part of the broader scope of the regional plan which is involved with various socioeconomic considerations. Nevertheless, it is a useful source of information.

The second report (U.S. Army Corps of Engineers District, Seattle 1975) is based on the environmental evaluation of the Willapa River and Harbor prepared by Northwest Environmental Consultants (1974). With the exception of the benthic data (referred to in the following paragraphs), this report has also been prepared from already existing sources.

While both these reports are useful summaries, they are for the most part secondary compilations, and their cited sources serve only to indicate how little has actually been done in Willapa Bay. The bay is not only comparatively pristine and unpolluted, it is unstudied.

The most comprehensive environmental studies in the vicinity of Willapa Bay have been those supported by the Atomic Energy Commission in relation to the distribution and fate of radioactive contamination in the Columbia River from the Hanford Works. These studies involved two major oceanographic institutions, at the University of Washington and Oregon State. For several years, support of this work was a substantial part of the budget of the oceanography departments of these institutions, and the major findings were combined in Pruter and Alverson (1972). Although Willapa Bay is mentioned specifically only a few times in this work, it includes discussions about radionuclides in sediments by M. Grant Gross (with earlier references) and of the effects of certain radionuclides on the larvae of the Pacific oyster by Victor A. Nelson (chapter 32), who begins his paper:

"The greatest potential hazard to man from Hanford-produced radionuclides introduced into the marine environment via the Columbia River is the uptake of these radionuclides by Willapa Bay oysters. The possible effect of these radionuclides upon the oyster itself is also an important consideration. The reasons are threefold: (1) Willapa Bay is the site of an important oyster fishery, (2) a considerable quantity of Columbia River water enters Willapa Bay 40 km north of the mouth of the Columbia River, and (3) oysters have a great capacity for the uptake of zinc" (Nelson 1972: pp. 819-820).

The close relationship between events in the Columbia River and the oysters of Willapa Bay was noted in 1960 in the initial article about the recycling of Zinc-65 from Hanford through Willapa Bay oysters to a Hanford employee who ate the oysters. Other than the efforts of geologists concerned with sediments, there has been no serious research on the intimate relationship between the water quality of Willapa Bay and events in the Columbia River.

In the bay itself, the research program has included monitoring water quality monthly at a series of stations, some thermographic records, and a regular sampling program for oyster larvae. The status of research in Willapa Bay up to 1974 is best summarized by these excerpts from the Willapa Bay Water Quality Management Plan:

"The Willapa Bay Shellfish Laboratory of the State Department of Fisheries gathers temperature and salinity data on a routine basis. Two recording thermometers are used, one at the Nahcotta mooring basin and the other at the National Wildlife Refuge station dock. Salinity, temperature and turbidity are recorded on weekly trips around Long Island and on monthly trips to a series of stations extending to South Bend in the Willapa River estuary. There are many years of temperature and salinity data available.

"The monthly hydrographic trips from the Shellfish Laboratory are now also used to collect background data to establish general standards of water quality in Willapa Bay. These include the following: temperature, salinity, conductivity, turbidity, light transmittance, pH, dissolved oxygen, iron, manganese, nitrogen, phosphate, and tannin/lignin. These physical and chemical analyses are taken at 15 stations extending from South Bend to the southern part of Willapa Bay. This series began in July 1972. These data will be useful for evaluating trends only after some years have gone by. At present, it is not possible to derive any conclusions except that the quality of Willapa Bay is, for the most part, excellent.

"There is at least one major water quality problem area in Willapa Bay. It is near the mouth of the Willapa River. The problem has displayed itself as an increase in oyster mortality as the mouth of the river is approached. Investigations have been made as far back as 1963 to determine the cause of increased mortality without any clearcut success. The Willapa Bay Shellfish Laboratory is now working on the problem. A recent theory is that the oyster mortality is connected to the accelerated growth of certain types of plankton, which in turn is related to the combined effects of leachate from wood-wastes and nutrients from sewage treatment plants. But this is as yet only a hypothesis.

"A project was organized to conduct an intensive study during the summer and fall of 1973 of conditions in the lower Willapa River and on the oyster beds near the river's mouth. The objective was to identify the causes of increased oyster mortality. The project was carried out jointly by the Willapa Harbor Oyster Growers Association, Washington Sea Grant, Grays Harbor College and the Regional Planning Council. Considerable staff and laboratory time was donated to the project. Project funds were devoted primarily to wages for students doing the sampling. Water quality data collected by the Shellfish Laboratory on a monthly sampling schedule between 1964 and 1968 were to be analyzed also. The results of the study did not identify the causes of oyster mortality, probably because no unusual increases in mortality took place that summer. The sampling which took place in the Willapa River itself, near South Bend, showed dissolved oxygen levels somewhat higher than those observed in the DOE and EPA surveys in 1970, 1971 and 1972" (Pacific County Regional Planning Council 1974: pp. III-26-27).

A study was conducted from 1965 through 1968 to determine the level of DDT pollution in Willapa Bay, in Grays Harbor, and in the Puget Sound area. The concentration of DDT residues in samples of Pacific oysters was used as a measure of the level of DDT pollution. The overall incidence of detectable DDT residues in all Washington samples was only 11%. Analytical data were too few to indicate any trends in DDT pollution. The program was discontinued after 3 years because of the absence of detectable DDT residues in most samples, this being due to the absence of DDT pollution and not because of any lack of sensitivity on the part of the monitored species.

The data derived from the above study was also analyzed by Dr. Arnold Shotwell of the Bay Center Mariculture Company. His observations are summarized in the following paragraphs:

". . . It appears that the most frequent occurrences and the highest concentration of DDT occur near the entrance to the Bay and become less

proceeding south in the Bay. This suggests that the pollution source is outside the Bay, so DDT is introduced through tidal action. This assumes that the South Bend sample is representative and not a hydrographic quirk. Otherwise, there would be some suspicion of a source in the Willapa River drainage. The higher concentrations at Stony Point will create the possibility of such a source.

"The exterior source of DDT would most likely be the Columbia River Plume. It tends to be southerly in its distribution during the months of March through September, when most of the positive samples show up, but even in the summer it still provides a source of pollution to the Bay. The summer occurrences may simply reflect the usage times of DDT. Very little DDT is used in the winter, so that the only results expected then would be from build-ups in tissue which had been retained. The results may then simply emphasize how the quality of the Bay depends on the quality of the Columbia River discharge.

"Taken as a whole, the Willapa Bay estuary is said to be one of the best - if not the best - major estuaries in the United States in terms of water quality" (Shotwell 1977).

In connection with its environmental evaluation of the Willapa River and Harbor Project for the Corps of Engineers, Northwest Environmental Consultants conducted a benthic sampling program during July and August 1974. This appears to be the first effort to determine the distribution of conspicuous elements of the benthos (other than oysters) in Willapa Bay. Unfortunately, it is a preliminary study, limited to a series of stations from the mouth of the Willapa River to Raymond, and pairs of stations at Tokeland, Bay Center, and Nahcotta. The stations were obviously selected to yield information about the biota of dredged channels, and the sparseness of the macrofauna suggests restricted conditions. If such a study could be repeated over a year or so, especially if started immediately after channel dredging, it could possibly yield some interesting results, as suggested by a 2-year study of recolonization after dredging in a Long Island harbor (Kaplan et al. 1975). It is interesting to note that very fine fibers were recorded for the stations at Tokeland, Bay Center, and Nahcotta in July and August 1974. Can these be the same fibers, possible nylon-dacron, that became generally evident in Willapa Bay in the spring of 1974 and that might possibly have made their way into the bay, perhaps from the Columbia River during the summer of 1974? According to Arnold Shotwell, these fibers occur in concentrations of "several to the drop." What significance do they have? The Northwest Environmental Consultants report refers to fine wood fibers, but no analysis appears to have been made at this time.

RESEARCH ISSUES AND QUESTIONS

In this section, we consider some of the more significant questions about the environment of Willapa Bay, the possible ecosystem interrelationships, and the relationship of human activity to the natural state of affairs in the bay.

Although man has intruded upon this and every other natural system on the globe, these questions are addressed to their relation to the natural system of the bay, rather than to human socioeconomic considerations. To put it in another way, are we interested in Willapa Bay as a scientific problem, as an interesting environment for its own sake, or as an opportunity to manipulate it for our own ends? Perhaps this is not entirely a valid dichotomy. The entire thrust of our environmental protection concern is that in manipulating the environment, man must consider that such manipulation should be within the natural constraints of living systems.

WHAT IS THE IMPORTANCE OF EELGRASS?

Eelgrass (*Zostera marina*) stands are a conspicuous feature of Willapa Bay (Figure 13). Oystermen do not consider eelgrass of importance and often remove it so that oysters will grow. Available information suggests that removal of eelgrass could affect both the physical characteristics and nutrient quality of the bay. Eelgrass is not simply a marine pondweed that occurs in certain parts of the bay; it is a whole system of growth, catchment of detritus, support of microbial associations, source of oxygen by day and deprivation by night, the mainstay of small crustacea, and modifier of current and sedimentation patterns and nutrient regimes.

In a recent review, Thayer et al. (1975) enumerated the following characteristics of eelgrass communities: high growth rate and production, with epiphytes having a total biomass approaching the eelgrass itself; supplies detritus which supports microbial populations and contributes to the maintenance of an active sulfur cycle; reduces surface erosion and increases sedimentation of organic and inorganic materials; contributes phosphorous and nitrogen recycling by uptake from sediments through the roots and release through the leaves (McRoy and Barsdate 1970, McRoy and Goering 1974).

McRoy (1970) summarized information on standing stocks of eelgrass in the Northern Hemisphere. The highest recorded standing stock was reported from South Oyster Bay, New York, where great drifts of dead eelgrass accumulated annually on the shore and were considered a nuisance by local residents (Burkholder and Dohney 1968).

The importance of eelgrass in coastal ecosystems was emphasized in a "natural experiment" on both coasts of North America and in Europe during the 1930's. Most standing stocks of eelgrass were destroyed (Moffit and Cottam 1941), but the direct causes of the wasting disease that affected the plant are still not known (Thayer et al. 1975). However, the effects of this drastic decline in standing stocks were observed throughout the Western Hemisphere. Some of these efforts are summarized below.

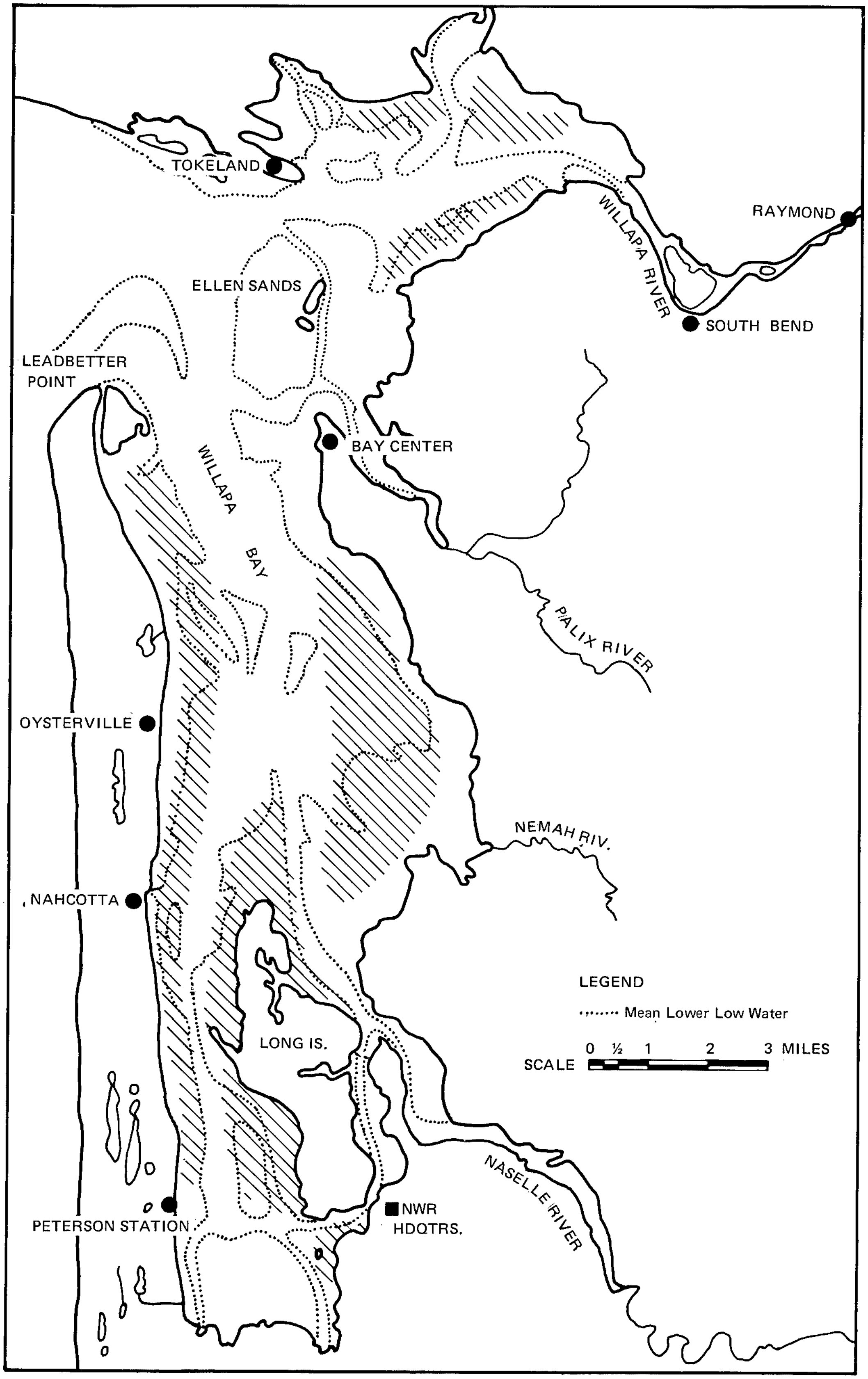


Figure 13. Eelgrass distribution in Willapa Bay. (U.S. Department of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife.)

Organisms whose major habitat was the eelgrass itself became rare or disappeared (Wilson 1928, Poulsen 1951), although some species survived on algae. Since the plant traps fine sediments and inhibits currents and wave action, the disappearance of eelgrass resulted in extensive changes in hydrography and bottom topography. Finer sediments washed away and coarser fractions remained (Wilson 1928, Cottam and Munro 1954). Infauna associated with coarser sediments invaded areas formerly occupied by eelgrass.

The east coast bay scallop, Aequipecten irradians, declined in many areas where its spat attached to eelgrass, but in some areas the spat survived on other vegetation. In one case, the improved circulation due to the eelgrass decline resulted in better distribution of nutrients and consequent development of a substantial bay scallop fishery (Johnson 1964). The eastern clams, Mya and Ensis, may also have been affected by loss of anchorage for spat (Johnson 1964). A flatfish fishery was ruined in an area inundated with muds from a former eelgrass bed (Wilson 1928). In the Jutland Limfjord, annual quantitative surveys of eelgrass were available prior to and spanning the eelgrass decline. These results showed no decline in numbers of benthic organisms except for a few species dependent directly on eelgrass (Blegvad 1951, Poulsen 1951). These results suggest that some fauna may not necessarily be dependent upon eelgrass as a source of nutrients.

Some shorebird populations may depend on eelgrass. Yocom and Keller (1961) analyzed food habits of waterfowl in Humboldt Bay, California, and found that of the seven most common birds using the bay (wigeon, black brandt, pintail, canvasback, coot, lesser scaup, greater scaup), eelgrass was the principal food of only black brandt and wigeon, the other species eating it only occasionally. The availably and acceptability of eelgrass as food, rather than dependence on it, accounted for its use by wigeon. It was concluded that eelgrass was the most important single food item for waterfowl passing through Humboldt Bay. However, this conclusion was derived from the fact that wigeon and black brandt represented respectively 47% and 20% of the total waterfowl population in the area, and eelgrass constituted 81% of the diets by volume of both birds.

Moffit (1941) noted the greater availability of substitute foods for brandt on the Pacific coast in comparison with the Atlantic. Green algae in the family Ulvaceae are abundant, though not of high food value. Phyllospadix is available in rocky areas and Salicornia in marshes. During eelgrass scarcity in Tomales Bay in 1940, brandt fed more in oceanic areas outside of the bay, and their diet was 51% Phyllospadix to 47% eelgrass, the percentage of the former being greater than in previous years. Reynolds (1966) reported sightings of black brandt in the Salton Sea feeding on alkali bush abundant at the time.

Eelgrass is a substrate for deposition of eggs by Pacific herring, Clupea harengus (Hardwick 1973), although the fish also use algae and worm tubes for this purpose. Most of the herring egg deposition probably takes place on algae and not on eelgrass, since it occurs in winter when the eelgrass is depleted.

The eelgrass community could be an important element in the maintenance of juvenile fish populations in the bay. First, the supply of detritus from

eelgrass may influence benthic populations, particularly small organisms such as amphipods and harpacticoid copepods. Feller and Kachynski (1975) found that juvenile chum salmon depend upon epibenthic prey in Puget Sound. Harpacticoid copepods were an important element in the diet. Siebert (unpublished data, Fisheries Research Board, Canada Biological Laboratory, Nanaimo) found many small benthic organisms to be very common in various juvenile salmon diets. Of particular interest was a harpacticoid copepod that was abundant both in benthic areas and in eelgrass beds. An interesting feature of eelgrass beds is a diurnal decrease in oxygen at night which causes many arthropods to leave temporarily, due to low oxygen levels (Dahl in Moore 1958). Broekhuysen (1935) found no oxygen in water of a Zostera bed at 5 a.m. and 260% of saturation at 3 p.m. Swartz (unpublished data, Pacific Marine Station, California) noted a decline in oxygen levels from saturation to 2 parts per million in the early morning in Tomales Bay eelgrass beds, coincident with extensive migration of caprellid amphipods from the beds. This suggests that eelgrass beds, as well as their periphery, could be important sources of fish food. Impacts of man on seagrass systems are reviewed by Thayer et al. (1975). One important effect is that eelgrass removal results in oxidation of bottom sediments so that recovery of eelgrass is impaired.

Four major benefits of eelgrass communities are suggested from the foregoing review: Eelgrass (1) has important hydrographic effects with resultant effects on sediments and associated biota; (2) is a source of detritus and hence might considerably affect food sources in deposit- and detritus-feeding benthic communities; (3) aids in recycling nutrients from sediments to water, and (4) may be important as a food source for fish populations.

TO WHAT EXTENT DOES RUNOFF FROM THE DRAINAGE BASIN INFLUENCE THE PRODUCTIVITY OR SEQUENCE OF BIOLOGICAL EVENTS IN WILLAPA BAY?

According to Northwest Environmental Consultants (1974: p. 19), "Because of the low volume of the runoff in relation to the tidal prism, the rivers are probably a relatively insignificant source of nutrients in the bay." This statement was modified in the Environmental Impact Statement prepared by the U.S. Army Corps of Engineers, Seattle District (1975) to read: "Extreme peaks in river flow are only 0.10 percent of the tidal prism, and thus do not suggest as great a contribution to the nutrient level of the bay by the rivers, as compared with that of the ocean." These statements do not seem to recognize that if there is a flushing time of as much as 20 days, the influence of river drainage may be much greater than its proportion to the tidal prism (a daily phenomenon) may suggest. Further, this would imply that there may be little danger to the system from the use of potentially dangerous chemicals in silvicultural practices in the drainage areas, which may not be the case if low concentrations of the chemicals are effective against certain organisms. If the mortality of oysters, especially near the Willapa River influence, is related to nutrient concentrations in the river that produced toxic phytoplankton blooms, as suggested by researchers in the Washington State Department of Fisheries (see Northwest Environmental Consultants 1974: p. 47), nutrient contribution from river drainage is significant.

The relationship between freshwater drainage and productivity in the bay must be examined in detail. This depends on understanding the tidal exchange,

flushing rate or residence time, and the current patterns in the bay. We do not know, for example, whether the cycle of growth and fattening of oysters depends more on contributions from the drainage area or from the tidal prism with respect to the upwelling in the nearby ocean. Spawning or larval survival of oysters may be influenced by the cold summer upwelling water, at least in the bay near the mouth, or influenced by the channel, as suggested by Duxbury (1970) on the basis of a set of data from 1954, uncorrected for tidal conditions. It is interesting that at the time these data were gathered, oyster production had steadily increased from the post-World War II low of 1950 to a peak in 1954, and that the general decline in production did not occur until after 1960. However, production records for oysters do not necessarily reflect a biological situation, such as variations in natural abundance. During poor years, oystermen may not harvest oysters, and oysters not harvested or processed within the State of Washington are not indicated in these production figures; a growing market in Portland and Astoria for Willapa Bay oysters is not recorded in these statistics, but rather in transport or export statistics that are difficult to compare. Nevertheless, the steady decline in oyster production in all areas in Washington since about 1965 strongly suggests some factor, economic or ecological, acting on all the oyster producing areas. The question concerning freshwater inflow and biological productivity in Willapa Bay is not clarified or resolved by the official oyster production statistics.

WHAT ARE THE EFFECTS OF DREDGING AND FILLING?

All estuaries in developed countries are subject to alteration, including loss of their marshlands and mud flats by filling, and the creation of channels by dredging. Usually, it is most convenient to deposit the spoil from channels on the mud flats and marshes. Willapa Bay has lost about 50% of its original wetlands to "progress" (Table 4). Raymond, the largest town in the basin, is built over a region of tidal channels (Figure 14).

The perennial question of the effect of dredging and associated filling will apparently be resolved, at least to a large extent, by the abandonment of maintenance dredging in the Willapa River and channel, in 1977. Without dredging, there will be no readily available source of material for filling. However, diking of marshlands, which alters patterns of sedimentation and accretion, is often used in the management of wetlands for improvement or maintenance of waterfowl habitat. While this practice is of obvious utility in upland freshwater or alkaline marshes to prevent drying up or to control water levels during summer and drought conditions, it should not be practiced haphazardly in tidal marshlands where it would separate the marshlands from their most significant physical influence - tidal action. This critical issue of the dredging and filling of marshlands is not addressed in the Environmental Impact Statement for the operations of the National Wildlife Refuge system (U.S. Fish and Wildlife Service 1975).

The notion that a tidal mud flat is of value only when covered with more mud and converted to town or pastureland ignores the significance of such tidal flats to the natural economy of the bay. The worms and clams, although they may have some small value to man as bait and food, are part of the food web in the bay system that is the basis for its general productivity and its

Table 4. Wetland[a] inventory (acres) of Willapa Bay (Shotwell 1977).

Area	Diked[b]	Undiked	Total	% Removed
North Cove		375	375	0
Kindred Slough- Cedar River	519	510	1029	50
North River	420	245	665	63
Lower Willapa	888	300	1188	75
South Bend	1630	18	1648	99
Raymond	438	915	1353	32
Porter Point	691	640	1331	52
Naselle River	532	643	1175	45
Nemah River	158	405	563	28
Palix River	548	575	1123	49
Niawiakum River		295	295	0
Wilson Point	42	8	50	84
Bone River		208	208	0
N. Stony Point		8	8	0
Long Island	143	318	461	31
Stanley Peninsula	40	10	50	80
Long Island Slough		32	32	0
Long Beach Peninsula	128	787	915	14
Totals	6177	6292	12469	50

[a] Wetlands referred to here are areas between mean high and highest high tide levels.

[b] Diked includes dikes, undiked fill, road grades, and other structures which effectively remove wetlands from the estuarine system.

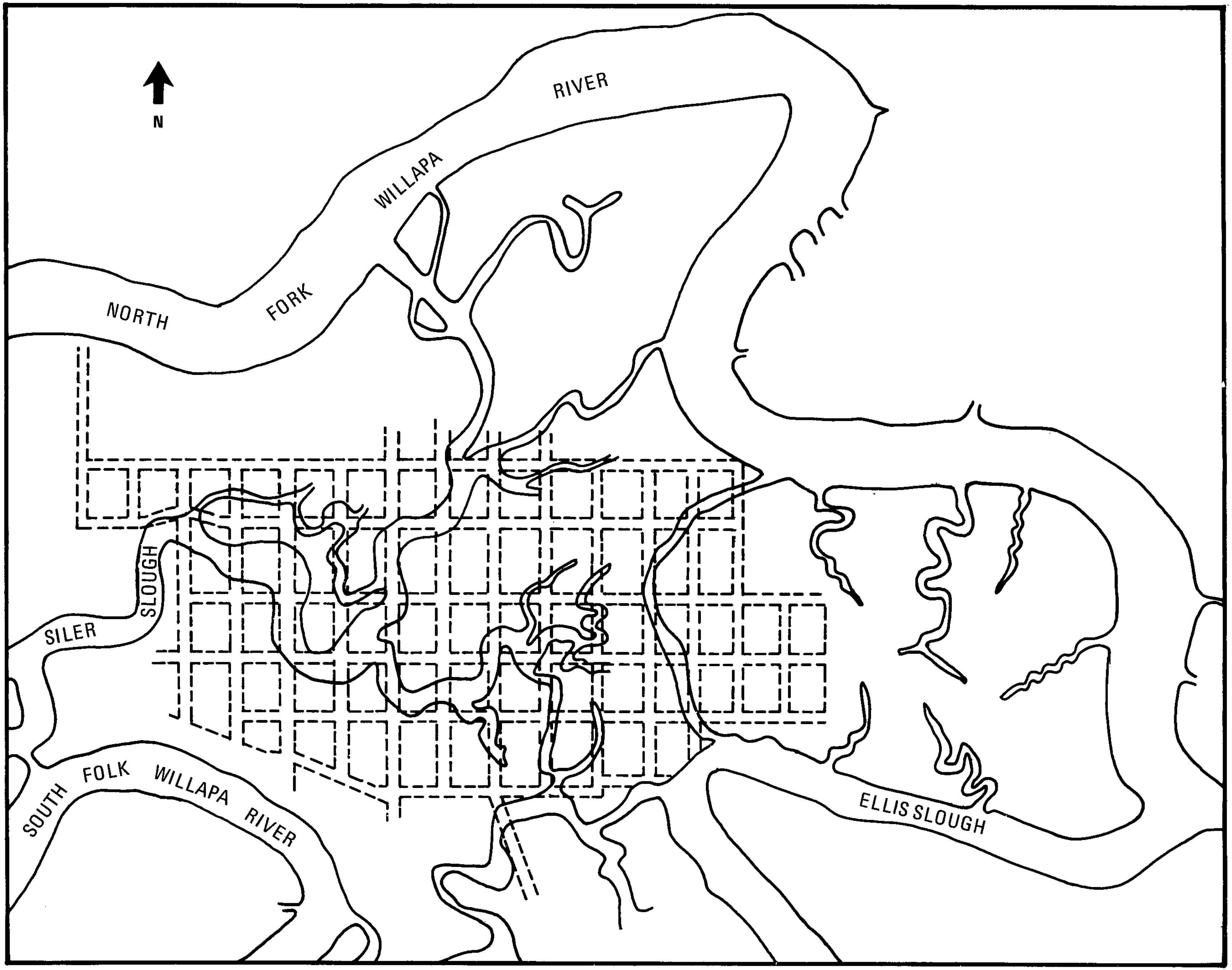


Figure 14. The city of Raymond superimposed over the original slough drainage pattern (Shotwell 1977).

ability to sustain a diversified exploitation of the larger organisms by man. A more significant aspect of the system may be the organisms and their activity at the sediment-water interface. The contribution to the bay system of this active layer of the upper few millimeters of sediment is still to be determined; indeed, we are only now becoming aware of its significance. See MacIntyre (1974) and the startling photographs in Sieburth (1975).

Marshlands must be assumed to be equally significant hotbeds of interstitial and interface activity. Although the higher marshes are not reached by every high tide, contributions during high tides may be significant to the natural economy of the bay.

In the context of these suspicions, two questions are especially pertinent. What would be the comparative significance to the system of marshlands (and tidal flats) if these areas were reduced to strips along dikes, as opposed to the present scattered, irregular patches? And, does it improve a tidal marsh for species, such as waterfowl, to "stabilize" it behind dikes that control tidal waters so there is a more constant inundation than provided by nature?

Alterations of natural habitats can only be maintained by constant vigil and continual expenditure of energy. Unless constantly controlled, a diked marsh will inevitably turn into a meadowland by processes of accretion, depending upon the sediment loads of the contributing drainages. The long-term effect of such activity can be the ultimate reduction of the estuary and its associated wildlife.

WHY ARE SOME AREAS OF WILLAPA BAY FAVORABLE FOR THE GROWTH OF OYSTERS, AND OTHERS FOR FATTENING?

Some areas in Willapa Bay are better for the production of seed oysters and growth of young oysters, while others, known as fattening grounds are more favorable for producing oysters for market (Figures 15, 16, 17). The Washington State Tax Commission has developed a classification of the various grades of oyster lands in Willapa Bay (Table 5).

The seed-catching and growing areas for oysters are in the lower half of Willapa Bay, approximately from Nahcotta south, primarily above the mean lower low water, while the fattening areas occur generally in the shoals northward, and to east of Ellen Sands. This suggests some relation to tidal circulation and distribution of nutrient factors, trace substances, and perhaps suspended materials in the water. The division between growing and fattening areas is not clear cut, however, and in some parts of the bay there may be a mosaic or reticulate pattern. The areas may vary each year so that a fattening ground one year may be a growing ground in another year. Since we do not know what the nutritive requirements of oysters really are, it is difficult to suggest anything more refined than a shotgun approach to the problem, although an understanding of the factors that produce this differential reaction in oysters would be valuable to the oyster growers of Willapa Bay.

While information is lacking about the natural state of oysters in 1851 at the beginning of the industry, there is some implication that, in general,

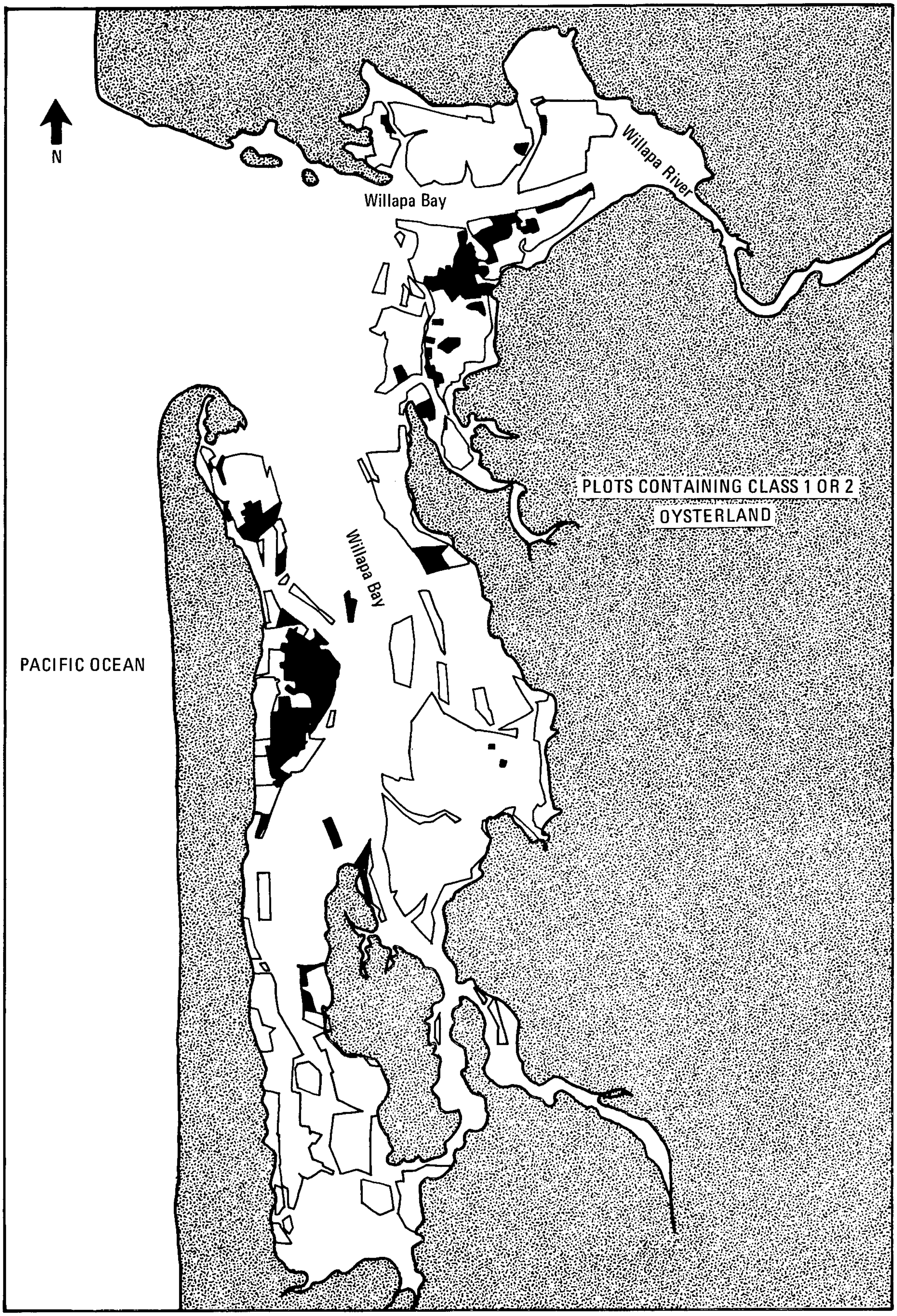


Figure 15. Oyster fattening land in Willapa Bay (Shotwell 1977).

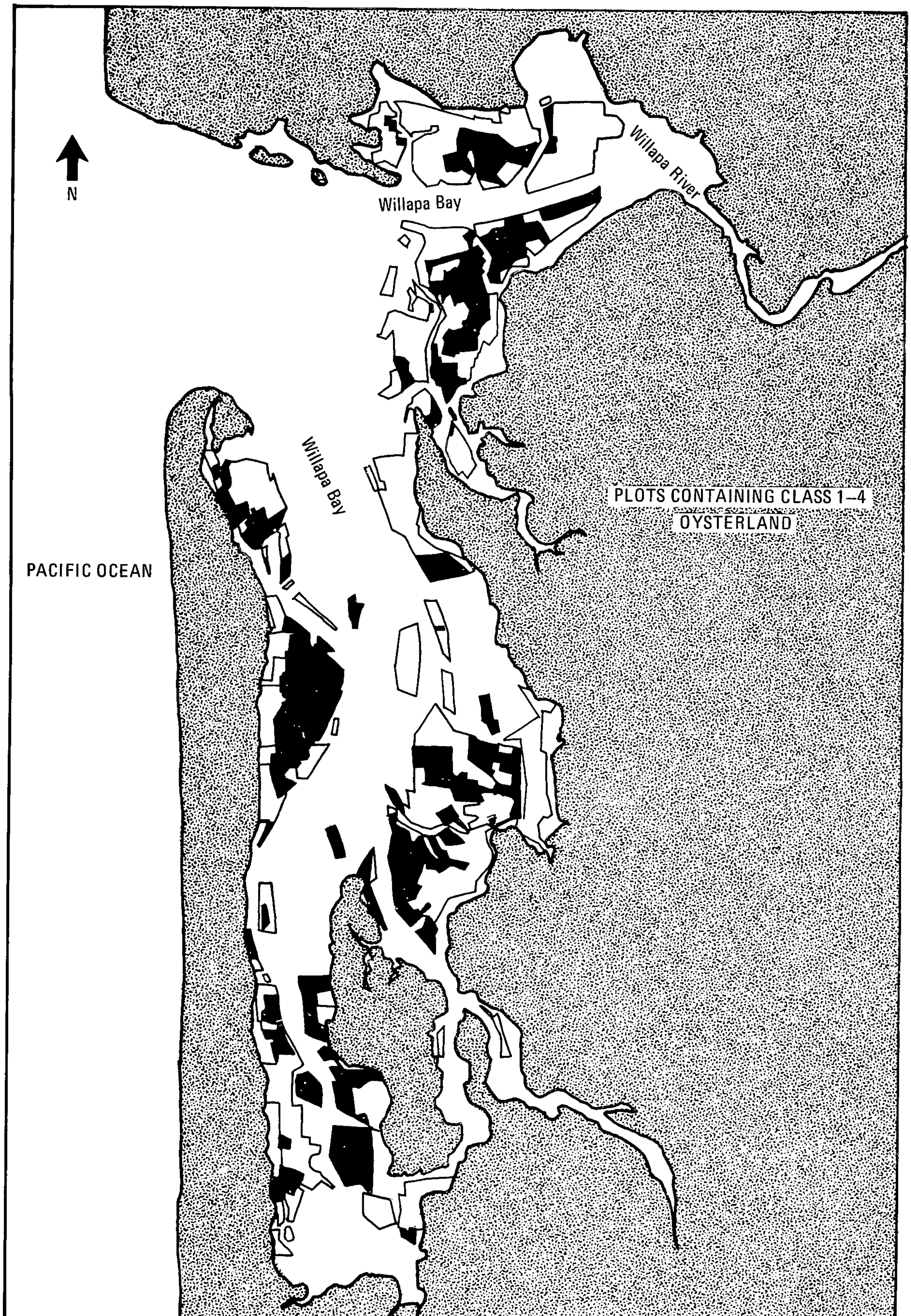


Figure 16. Productive oysterland in Willapa Bay (Shotwell 1977).

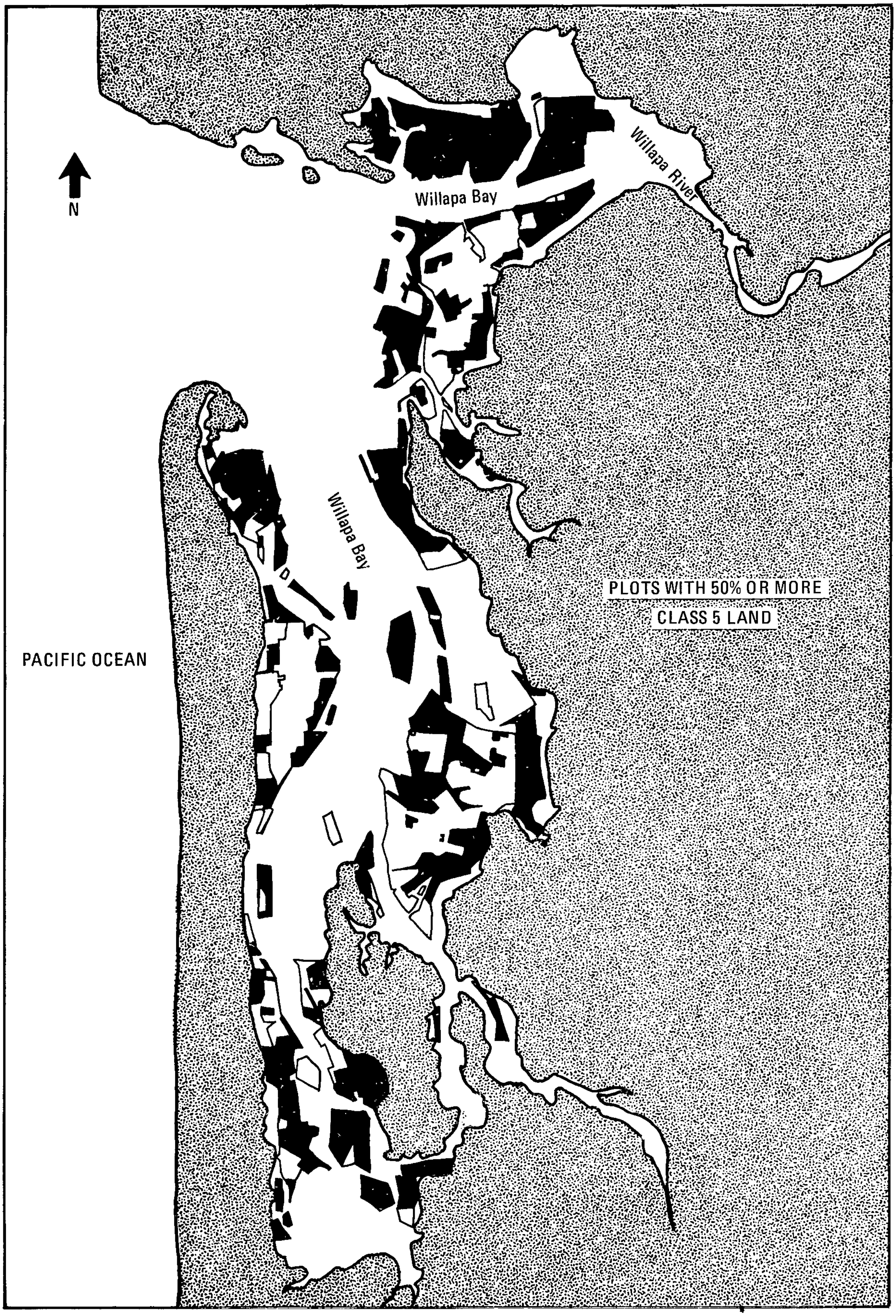


Figure 17. Non-productive oysterland in Willapa Bay (Shotwell 1977).

Table 5. Oysterland classification (Shotwell 1977).

Classes	Description
I	Oyster production or growing land is used in producing marketable oysters. Generally located where there is good circulation of water and plenty of feed available. This is the very best land in the bay. The seed and marginal land will be generally located between the production land and the shoreline.
II	Oyster production land or growing land has the same general characteristic as class one. The biggest difference is the amount of food available, which limits the production of marketable oysters.
III	Oyster seed land is used for the catching, holding, or development of oysters. Generally speaking, the area is located between production land and marginal land. The available food supply and the amount of time it is not covered by water usually determines how good it is.
IV	Oyster seed land is used for the same purpose as class three; however, it generally will not support very much of a seed crop as it is very closely related to the marginal land. It has a very poor supply of food.
V	Oyster marginal land is located between the shoreline and the seed area; however, it may be found any place in the seed or production area. It is of little value other than as for protection for the other class beds.

the distribution of growing and fattening grounds may not have changed conspicuously, especially during the eras of the Eastern and Pacific oysters. The best statement of the history of oystering in Willapa Bay up to some 30 years ago is found in Chapman and Esveldt (1943):

"Willapa Bay has long been noted as an oyster producing area. It was originally heavily populated with the native oyster, Ostrea lurida. Starting in 1851, lumber schooners with deck cargoes of oysters sailed regularly to San Francisco and the business grew rapidly, reaching a peak in the 1870's and then declining slowly. Most of this business was simply a gathering of wild oysters. In later years, however, the oysters were brought from the wild beds, where the spat caught, and were planted on choicer plots for fattening, but the cultivation of the native oyster population in Willapa Bay and the increases of intensive cultivation of the oysters in the Olympia area gradually crowded Willapa Bay completely out of the native oyster business.

"In 1894, 80 barrels of adult Eastern oysters, Crassostrea virginica, were planted in the Palix River and did well. In a few years, large plantings of the seed of this species were made and the oyster business in the Bay once again came to life. From 1902 until 1919, the Eastern oyster business went along with normal fluctuations. While the species propagated to some extent in the mouth of the Naselle River, it never did so on a commercial scale and the industry was dependent upon seed from the East Coast. The difficulty of getting seed during the last war, coupled with a malady of unknown origin which struck the adult disastrously, led to the abandonment of this industry, and an occasional Eastern oyster in the dredge is all that remains of it today. They still reproduce to a slight extent in the lower Naselle area.

"In 1928, the seeds of the Pacific oyster were introduced and the third and greatest phase of the oyster industry in Willapa Bay began. The first Pacific oysters that were planted grew at a tremendous rate. Some were marketed nine months after the seed was planted and a year after planting they were comparable in size to medium Eastern oysters. Besides the rapid growth rate, they proved to be much more hardy than either the native or Eastern oyster. Plantings were increased year by year until in 1935, 50,257 cases of seed were planted. The oysters were growing rapidly and fattening to marketable condition even in the southern end of the Bay. Then in 1936 occurred the tremendous natural set of Pacific oysters, when in nearly all parts of the Bay, and especially in the southern end, the growing oysters as well as rocks, pilings, and other objects were plastered with seed.

"Very quickly, conditions began to change in the Bay. The growth rate slowed down markedly all over the Bay until oysters were taking three years to reach marketable size instead of one or two years, and in many areas, especially in the southern end, the oysters would not fatten to a marketable condition at all. These conditions still remain and considerable areas which formerly produced marketable oysters have been abandoned. Since it was not economical to move them, large beds have remained unworked with generation piling upon generation until acre after acre was almost a single solid clump of oysters, with the oysters in an exeedingly poor and watery condition. Other oystermen who had good fattening grounds in the Oysterville, Stackpole, or Bay Center areas replanted their poor oysters to the better grounds where in a few months they would attain a marketable condition.

"It was well-known among the oystermen that if an imaginary line were drawn angling across Willapa Bay from the south quarter of the Nemah State Oyster Reserve on the east in a southwesterly direction down the channel west of Long Island through the Middle Sands to the west shore a mile or so south of Nahcotta that the best setting grounds would be south and east of this line and the best fattening and growing grounds would be north and west of it. This had been true with the Eastern oyster, true in considerable measure with the native oyster, and a brief survey showed it to be obvious with the Pacific oyster."

The foregoing events suggest a tentative hypothesis concerning the factors leading to the existence of fattening and growing areas for oysters in Willapa Bay and tentative management policies for improving oyster production.

It is noted that the fattening areas are closer to the entrance of the bay and the growing areas are in the upper portions of the southern reaches. If oyster densities are sufficiently high to remove significant proportions of oyster food organisms from water passing over the beds, it is likely that oysters near the entrance will remove enough food to affect food availability in the upper parts of the bay. This is likely since the tidal prism is so large; the oyster population probably depends entirely on resources coming in with the tides. It is significant that rapid oyster growth to marketable size decreased after the massive spatfall of 1936. This indicates a possible correlation between oyster growth, fattening rate, and density. It is also of interest that oysters have remained in the bay at high densitites with the attendant poor growth performance. If this density-dependent growth and fattening hypothesis is true, then a clear solution to the present problem is imminent, namely the removal of large numbers of oysters that are not being harvested from the bay by dredging or other methods. This would reduce oyster densities and make more food available for the remaining populations, subsequently improving both growth and fattening rates.

The natural history of oyster growth needs more attention. It is possible that when food abundance per oyster is adequate, the oyster will fatten rather than increase in size.

WHAT IS THE SIGNIFICANCE OF MICROORGANISMS?

In every textbook of ecology and most introductory biology books, there are food chain and pyramid-of-numbers diagrams that imply the controlling significance of the small, rapidly reproducing organisms such as diatoms, bacteria, protozoa, "reducers," "decomposers," and the like. Some attempts at quantifying this microbial element suggest that by numbers, total weights, and rates of turnovers, it may be the controlling factor in the natural system. Yet this oft-stated implication has been ignored in field studies. Quite possibly, this may be associated with our lack of comprehension of the interface phenomenon in which the microbial element of the ecosystem thrives and functions. This is also related to our method of taking samples and treating material for study. The unidentifiable crud and very small organisms are disturbed, stirred up, and washed away so as to make the identification and enumeration of the larger organisms (usually at least 2 mm or more long, or round) possible.

The living system is very different. A mud flat or the surface of vegetation, oyster shells and rocks in a bay, or the sea, is a living surface, inhabited by all sorts of minute creatures, including the larval stages of oysters and other invertebrates in season. The relation of the active layer of living material to the larger elements of the benthos is as yet undemonstrated. Yet it may be the composition and condition of this layer that govern in large part the success or failure of such benthic stocks as oysters, including the nature and condition of this living surface on the shells of the larger oysters themselves.

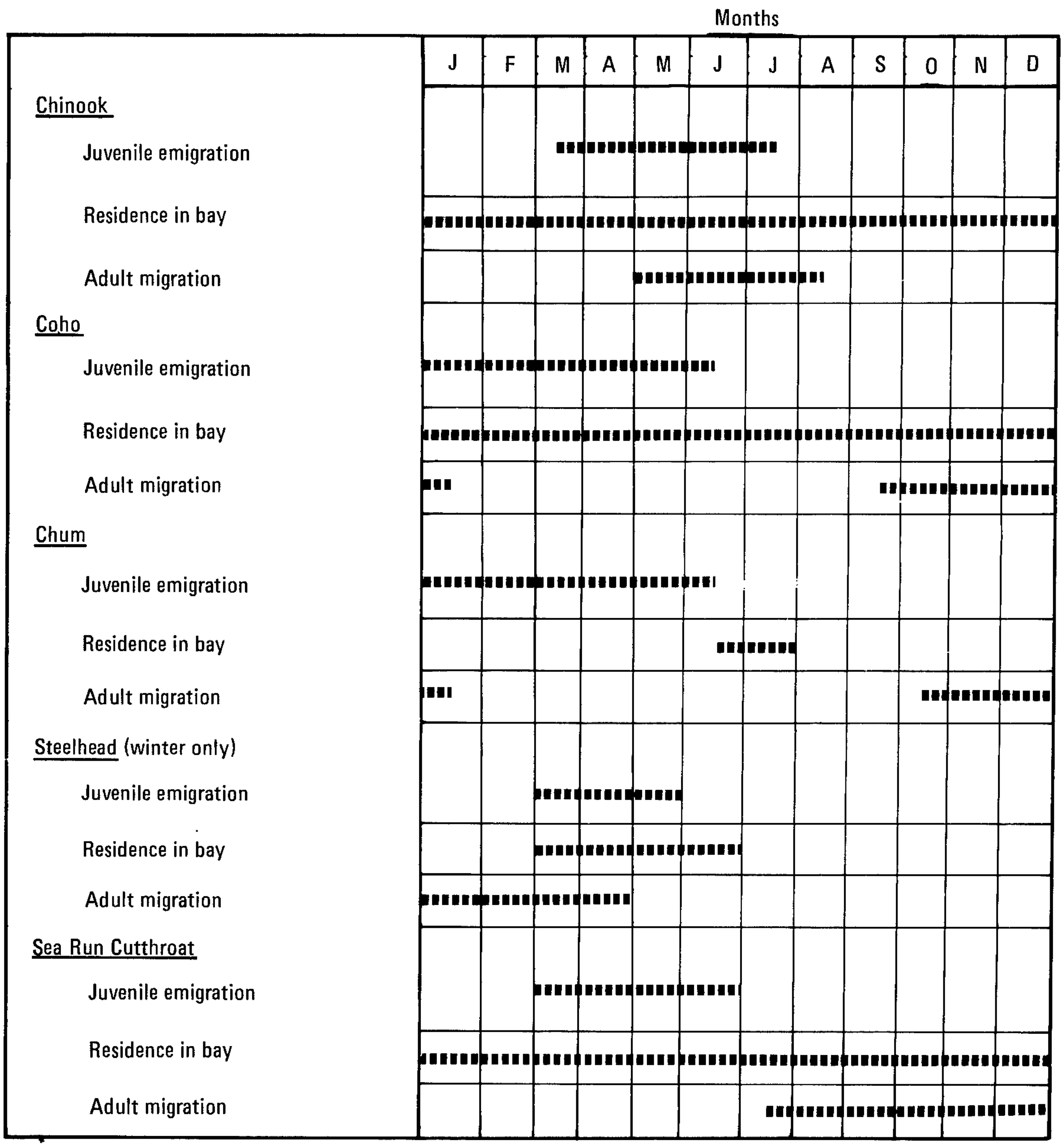
Investigation of this "microbial seascape" will require new techniques and approaches, especially in obtaining undisturbed samples of the surface and in maintaining such samples in aquaria to determine the specific composition and relative abundances of the organisms involved. In this category, we should probably include much of the so-called meiofauna, the creatures of less than perhaps 5 mm in total size. Many of these are worm-like and pass easily through seives as fine as 0.5 mm, especially when living. Although the gathering and possible identification of such organisms are now being required in some pollution surveys and environmental monitoring programs, it is obvious that we need to know more about how these organisms function in nature, especially in relation to each other, before their significance can be clearly assessed. Long species lists of minute and microscopic organisms are about as useful as the names in a telephone book in conveying a clear sense of what is going on in a community.

WHAT IS THE RELATIONSHIP BETWEEN SEASONAL SUCCESSION AND CLIMATIC VARIATION?

The only information we have for this important aspect of life in Willapa Bay is the type of data summarized in Figure 18 for the various stages and species of salmonids in the bay. The differences in temperature requirements of the various species are not great enough to explain the different periods of juvenile migration or presence in the bay. Possibly this progression is related to the kinds of food available to juveniles.

There are obvious relationships between the progression of the seasons and changing species of phytoplankton. (See Miller 1974 for an indication of how two closely related species of copepods may indicate the changes in water quality in an Oregon bay.) Work in eastern estuaries suggests a regular progression through the seasons of phytoplankton and of associated species of copepods, usually in congeneric pairs. The variations in the zooplankton content of Willapa Bay do not appear to be clearly related to the requirements of the various species of salmonids, but this observation may reflect a paucity of investigation rather than actual circumstances.

Recent studies show that many fisheries are dependent upon regional variation in climate. In the Gulf of Maine, catches of 10 to 17 commercial marine fish and shellfish species were found to be significantly correlated with sea temperature (Sutcliffe et al. 1977). Determination of the direct causes of these correlations required detailed studies of the biology of particular species. For instance, abundance of the soft shell clam (*Mya arenaria*) may be affected by predatory crabs that are more abundant in warm years. Information about the biological effects of ocean variability in the Northeast Pacific is



For further information see Phinney and Bucknell 1975.

Figure 18. Timing of salmonid presence in Willapa Bay and tributaries (Washington Department of Fisheries 1973, Washington Department of Game unpubl. data).

reviewed by Lasker (1978a). Monthly upwelling indexes have been correlated with Dungeness crab abundances (Peterson 1973, Botsford and Wickman 1975). Increasing catches were correlated with increased upwelling with lag times of 6 months to 1.5 years. Annual variations in zooplankton are associated with upwelling (Peterson and Miller 1975). Increased coastal upwelling in Pacific mackerel spawning areas, just before or during the spawning season, increased recruitment while increased offshore convergence had the opposite effect (Parrish 1976). Nearly 80% of the variation in mackerel recruitment could be attributed to environmental factors. However, anchovy recruitment appears to be inhibited by strong upwelling because dense larval food patches are broken up and dinoflagellates are replaced by small diatoms (Lasker 1978b). Wickett (1975) found that over 70% of the variation in percentage of returning salmon could be attributed to the amount of freshwater discharge from the Fraser River and wind stress forcing freshwater against the coast of Vancouver Island, British Columbia. In even-year pink salmon, 89% of variation in stock size could be related to rainfall at spawning and the hours of bright sunlight at the time fry were moving offshore (Lasker 1978a). Other examples of the effects of long-term climatic and oceanographic variation on fisheries throughout the world are reported in Volumes 172 and 173 of the "Rapports et Process-Verbaux des Reunions Conseil International pour l'Exploration de la Mer."

Intrinsic biological characteristics of particular fisheries must also be taken into account. Botsford and Wickam (1978) proposed a model of the Dungeness crab fishery in which older age groups affect the survival of younger crabs. Size-selective fishing was shown to decrease population stability under certain conditions, and the cyclic behavior of the northern California fishery was found to correspond to an unstable mode in the model. Biological studies that would help confirm the applicability of their model were suggested by the authors. Similar studies might be very useful for understanding variations in crab catches in the Willapa Bay region.

Fisheries enhancement projects can be improved with additional biological knowledge. Peterman and Gatto (1978) showed that in some instances, salmon enhancement projects may only increase the proportion of fish eaten by predators rather than that caught in the fishery, the success of enhancement depending upon functional responses of predators to increasing densities of fry. Peterman (1978) showed that some salmon stocks will not produce increases in adult returns with increased smolt abundance because marine survival rates are affected by abundance of other cohorts or stocks. Data on within- and between-cohort and between stock (in nearby and distant rivers) interactions is needed to determine the significance of density-dependent survival in ocean salmon populations.

While regional environmental factors and biological interactions can be important, economic and decisionmaking uncertainties may also be important in management considerations. Biological, economic, and management considerations have recently been subjected to mathematical treatments (Holling 1978). The mathematics are often complex and managers must also deal with gaps in the data and pressure from different interests. A certain amount of error is inevitable in adopting management strategies since managers must adapt to changing biological, economic, and political conditions (see Peterman et al.

1978). The foregoing review suggests that combined local and regional biological studies with appropriately developed management strategies are needed to improve particular fishery management practices. New methods and findings should be regularly incorporated into local practice, and experts should be found to help incorporate complex new methodology. Above all, management ought to be developed on a specific fishery basis, rather than in the context of a general local ecosystem study, especially if the local ecosystem is likely to be greatly affected by regional factors.

RATIONALE FOR FUTURE RESEARCH

Willapa Bay is one of the least, if not altogether so, impaired bays in North America. While it has been a productive area for oysters, it also supports many other fisheries and activities based on renewable resources, including timber harvesting and waterfowl hunting. Because of the compact relation between the water area (and volume) and the drainage area, it presents a unit amenable to intensive study and analysis. There is however, one qualification. Like all estuaries, its annual cycle of natural events is related to, when not an intimate part of, the hydrographic events in the adjoining coastal waters. In addition, this cycle of natural events is related to those of the Columbia River. Hence, understanding of this system also requires close attention to what is happening during those months when the Columbia River plume is a conspicuous part of the environment to the north of the river, and also to Grays Harbor where events and water conditions may influence Willapa Bay during the summer months when the Columbia plume drifts to the south.

The indication that the Corps of Engineers may abandon maintenance dredging of the channel to South Bend and Raymond is a recognition of changes already taking place in the timber industry. Virtually the entire Willapa drainage is now second growth or cut-over land; there are no big trees left for the old-fashioned mills to cut, and apparently these mills are not to be replaced by more modern equipment to handle the smaller size sorted logs which instead will be processed in other mills outside the Willapa basin.

This suggests that the economic future of Willapa Bay and its surrounding lands will be more modest than its past, and that it must rely on farming, fishing, oystering and sport hunting. To maintain this increasing dependence upon a diversified array of natural renewable resources requires a comprehensive understanding of the ecosystem. While the halting of dredging (and associated filling of tidelands) in Willapa Bay was not in response to environmental concerns, nevertheless, it provides an excellent opportunity to study the effects and economic consequences of a shift in emphasis from industrialization that may ensue elsewhere from pressures to maintain or restore environmental quality.

It is often stated that Willapa Bay is the most unspoiled of all estuaries on the Pacific coast. This is probably correct, since Tomales Bay, which has suffered less interference from man than Willapa Bay, is a marine rather than estuarine bay. Certainly, Willapa Bay is the most logical candidate for national estuary status above all others on the Pacific coast, although at present there appears to be little interest from the State of Washington in promoting such status for Willapa Bay. In any event, what is learned about Willapa Bay will be of value in understanding the other estuarine systems on the Pacific coast of North America, especially those in regions of high winter rainfall.

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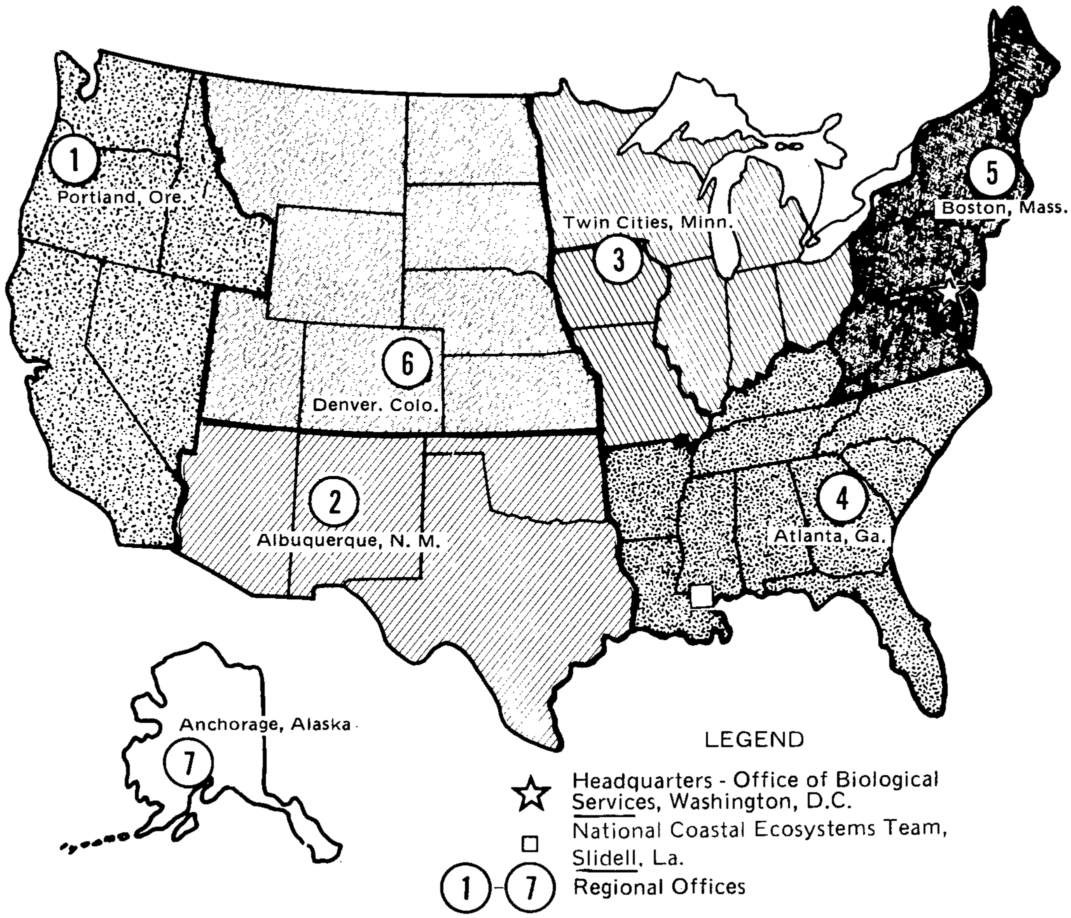

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